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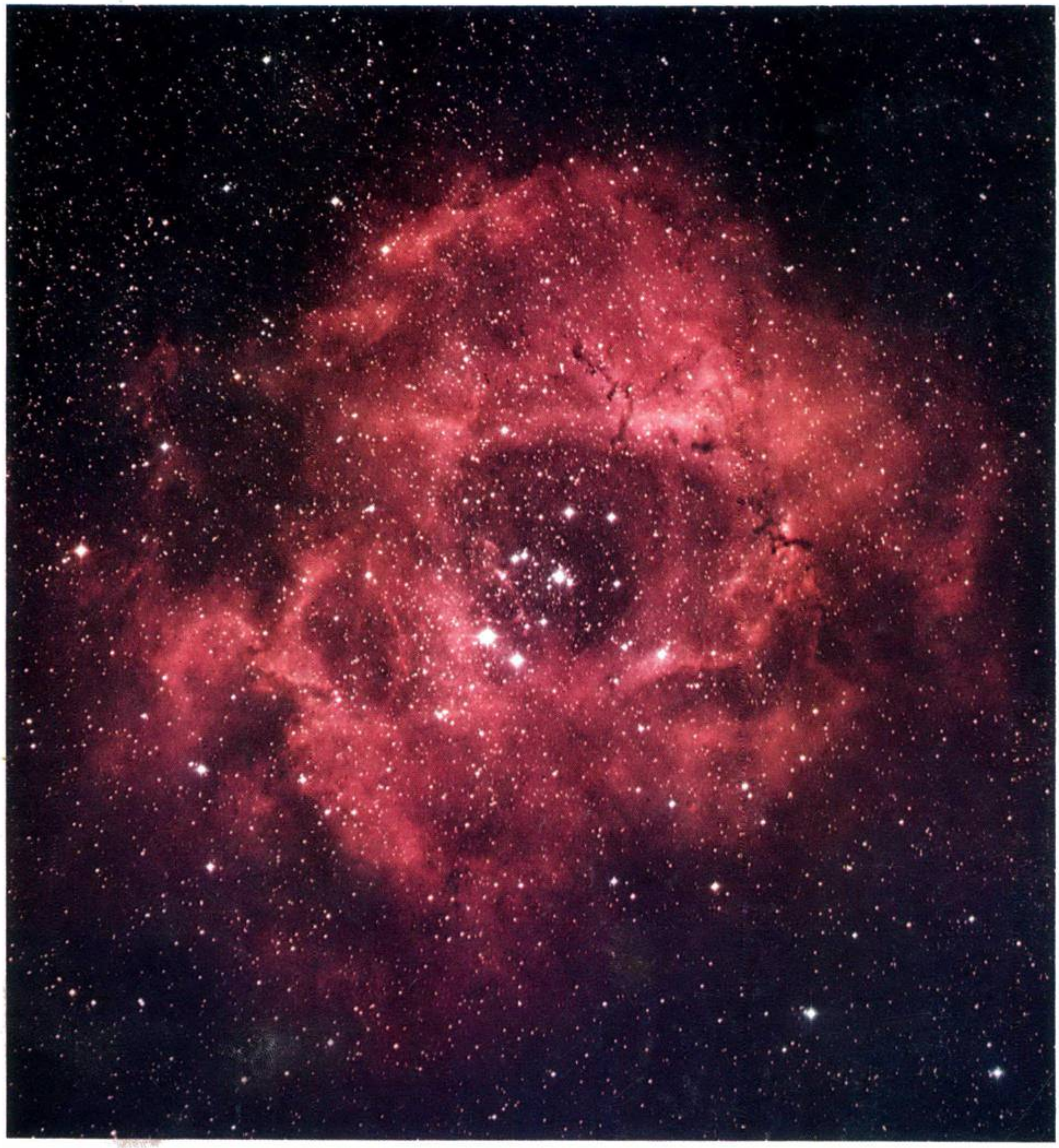

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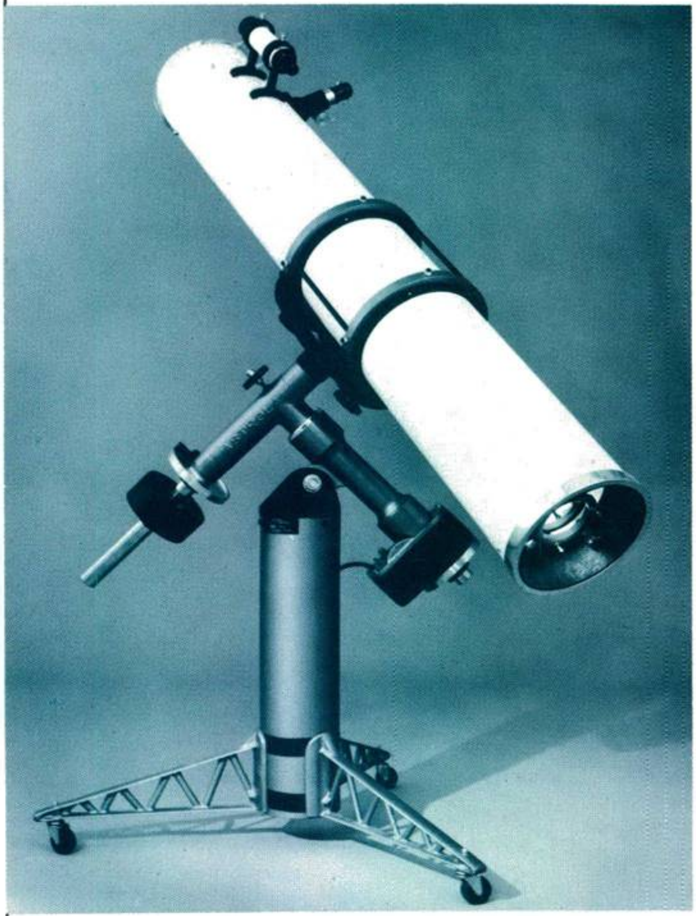

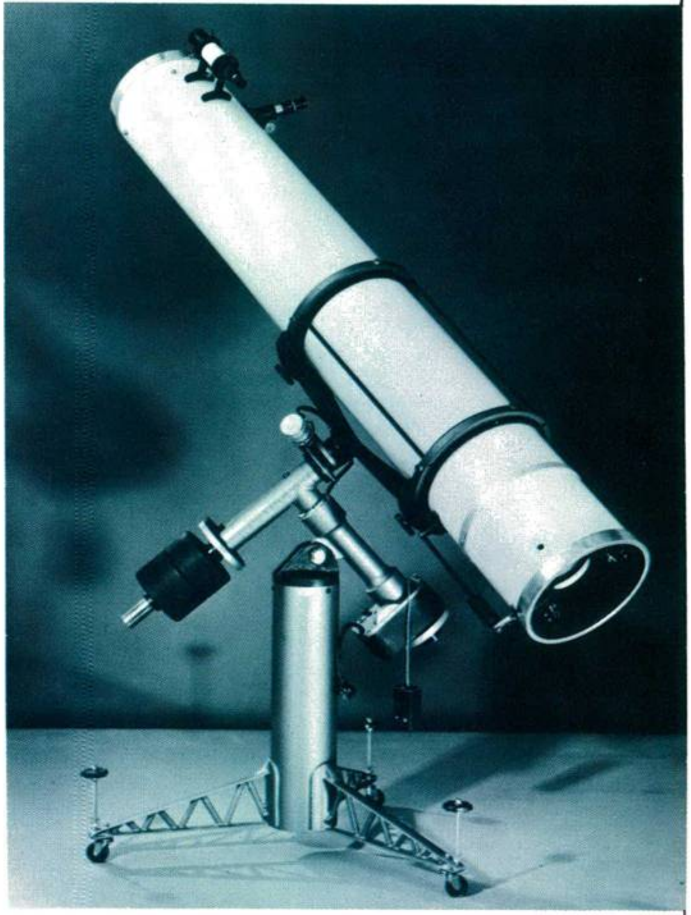

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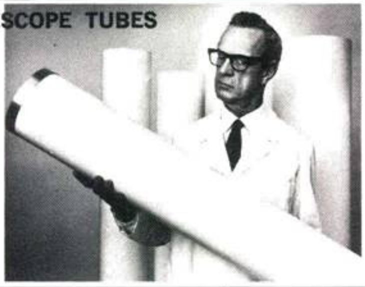

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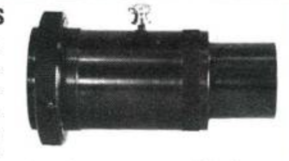

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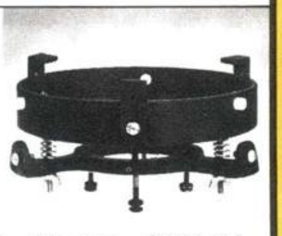

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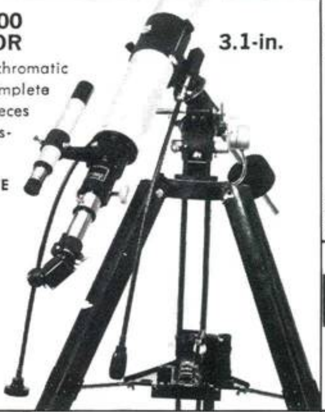

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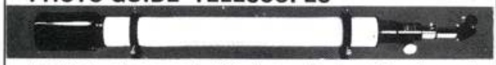

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Photograph © California Institute of Technology and Carnegie Institute of Washington

Mammoth clouds of dust and gas wrapped around a cluster of bright stars comprise the hauntingly beautiful Rosette nebula in the constellation Monoceros. Ultraviolet energy from these extremely hot stars stimulates the hydrogen clouds into glowing in shades of red and magenta. Etched over these bright clouds are black filaments of matter slowly condensing into stars, offering astronomers a dramatic peek at the process of star creation. The Rosette nebula is in reality a huge star factory, containing enough material for mass producing an estimated 11,000 stars. This month's lead article explores star birth and death.

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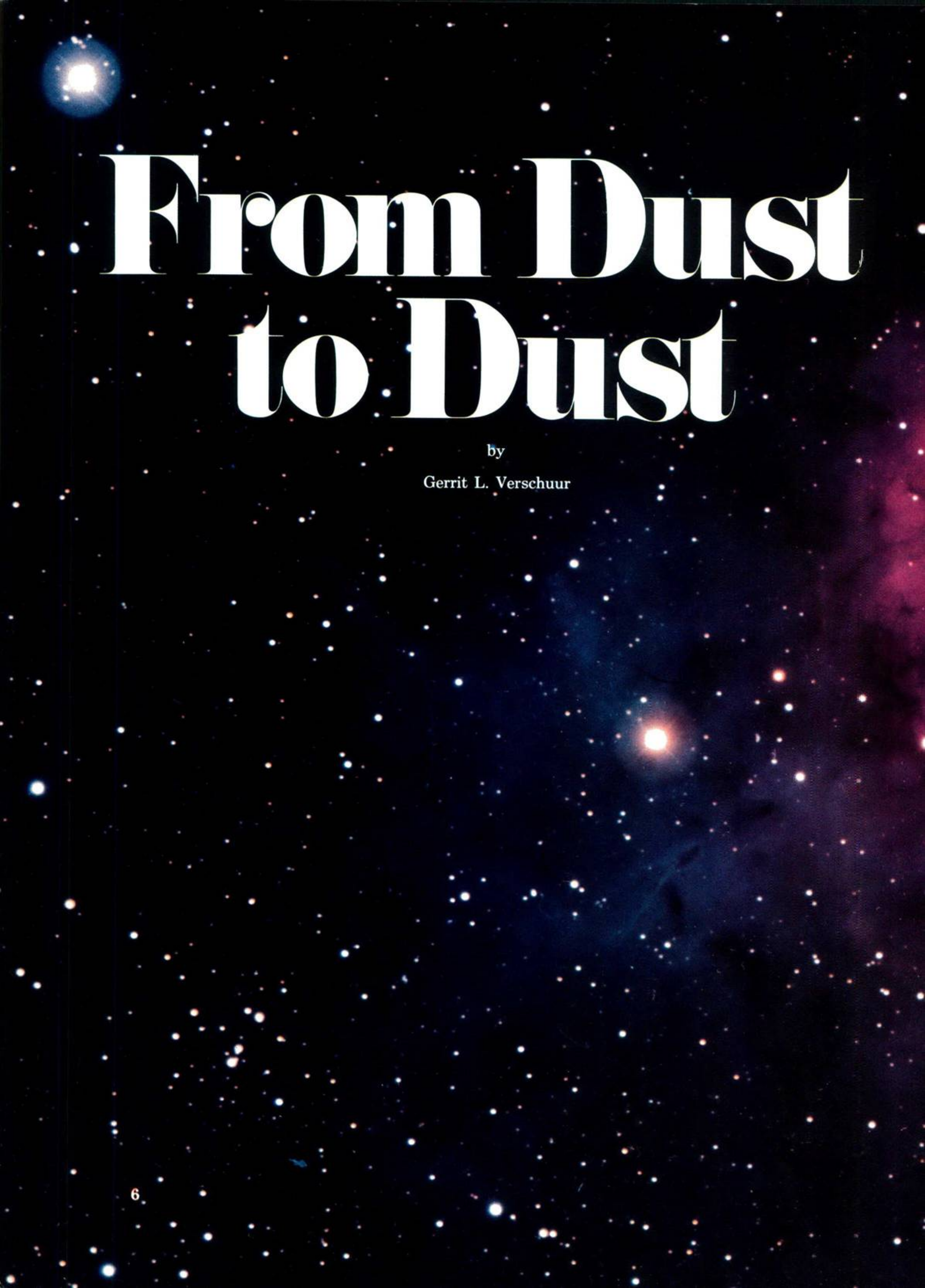


From Dust to Dust

by

Gerrit L. Verschuur

Nothing seems more permanent than the stars. Year after year the same stars, in the same constellations, shine as faithfully as the sun. With few exceptions, the stars you see tonight have been in the same locations for thousands of years — some for millions of years.

When the dinosaurs roamed Earth, the skies were somewhat different. There were probably more bright stars then, many of them closer together. But even then there were a lot of stars that have not changed since. A star lasts a long time before its supply of fuel is consumed and it dies quietly or explodes violently, depending only on its size (or so astronomers now believe).

Just like us, all stars are born, grow older and die. And just like us, what happens to the star during its lifetime determines what the next generation of stars will be like. As stars grow and die, so they spread newly processed material to the *interstellar medium* (the space between the stars) — material which will be used to form future generations of stars.

Astronomers glimpse the slow, tedious process of star creation within the Trifid nebula, 3,000 light-years beyond Earth. During the next few million years the Trifid's black cobwebs of dust will condense into hundreds of hot new stars. Already some recently ignited stars at the nebula's core are stimulating concentrations of hydrogen gas into a glowing red cosmic flower. What will the coming billions of years hold for these stellar newcomers to the galaxy? This article traces the lives of stars from birth to death — dust to dust.

Kitt Peak National Observatory Photograph

Hale Observatories Photograph © California Institute of Technology and the Carnegie Institute of Washington

Several hundred relatively youthful stars born no more than 20 million years ago comprise the magnificent Pleiades cluster in the constellation Taurus. The brightest stars are embedded in dust and gas that glows in the same way bright street lamps illuminate hazy air surrounding them. Squandering their fuel at incredibly fast rates, the brightest of the Pleiades' inhabitants are doomed to short lifetimes, lasting only millions instead of billions of years.

There was a time, before any stars were born, when the universe was mainly hydrogen gas with some helium and very little else. That was perhaps 15 billion years ago. Somehow stars were born and started to shine; the hydrogen gas was "cooked" to helium, and then to heavier elements as the stars grew hotter. In those early days of the universe there were probably no planets like Earth because there was so little of the heavy elements — no iron, no silicon, and little oxygen — and thus no solid planets.

But as time passed, these heavy elements were being brewed inside the stars and wafted or blasted out into space to create the dust clouds that we now see among the stars. These are the dust clouds which contain dozens — perhaps hundreds — of different molecules. Already 36 types have been found, and yet we still do not know what the dust itself is made of. We do know that stars are still being born. Yet there is no population explosion — because as stars are born, others die. There is a finite quantity of matter available in a galaxy, so the process will ultimately end.

Today more time and effort than ever before is being spent on trying to understand exactly every step in the evolution of stars. Let's begin with the clouds of gas and dust themselves and see what happens to them.

The modern astrophysicist attacks this problem by making a "model" of a cloud which can be fed into a computer. The computer is given various parameters — the known laws of nature — and is then run until it "gives birth" to a star. It all sounds rather magical, but the model is really only a mathematical formulation of the conditions that are thought to exist in the cloud before the star forms — the *protostellar cloud* as it is called. Since we can't watch a cloud for thousands of years to see what happens to it, this computer modeling is our only alternative.

The computer is fed both the physical parameters that describe the cloud and the equations that explain, according to presently known laws of the universe, the way in which matter will behave as time progresses. For example, we must consider how gravity balances rotation in a protostar, how heat generated inside the star can escape (whether by radiation or convection), and how the temperature depends on size.

Depending on the state of the star at any one time, the equations will predict what the next state will be. What will the temperature become if it is this hot now? How large will the star be next if it is now so large and so hot and so old? Such questions are fed into a computer and, as the computer ticks away, a second of computer time might be 1,000 years of star time. Finally, the researcher looks at the numbers that the computer prints out and compares them with the properties of real stars.

Throughout the galaxy we have a sample of stars of all ages. In a random sample of 1,000 stars we will find that some will be very young (maybe 100,000 years old), and others will be very old (perhaps 10 billion years). We measure their properties as best we can to determine their ages. Then we compare these quantities with those that were generated in the computer. We do not have to wait a billion years to watch the real star evolve so that we can compare it with our model. Nature has seen to that. We merely look out at a large sample of stars above us and then find all sorts of them already there — young stars, old stars, hot stars, cool stars.

It is just like taking a census here on Earth. If we want to find out about the evolution of humans we do not have to sit around and wait for 80 years. We can instead take a sample of one small city. We need to look at who is living there at any one instant: Count the number of babies, children and adults; weigh them, measure their heights, and find their ages. We will then have an instant pictorial summary of just how humans evolve. They start off young and tiny, and rapidly grow to maturity (spending about 50 years in that state); their sizes and weights change relatively little; then they die. Most of our sample of humans would be classed as adults, which obviously means that humans spend most of their lives as adults.

By looking at a group of stars (a *cluster* or an *association*, as such a group is called), we get a snapshot of the way stars evolve. We can see how long they stay in any given state. If most stars in our sample are a certain temperature and brightness, that means that a typical star will spend most of its life that way.

The existence of clusters and associations means that we have stars that have grown, or are still growing, out of one cloud of primeval gas. We can compare the properties of cluster stars with a larger sample of stars spread randomly about us — the so-called *field stars* — and we will find that they too show a similar distribution of ages, temperatures, masses and brightnesses. Because we are seeing the state of individual stars as they are now, this can be interpreted as a profile of the way stars in general evolve.

The careful reader might say that some of the stars are farther away than the others in our sample so that the light of those stars has taken longer to get to us. Those stars are, therefore, seen at a different time from the others, and we no longer have an instantaneous snapshot of the sample. Is our analogy of taking an instant census of a town incorrect? The stars are very close to us relative to their lifetimes. Most stars are at least hundreds of thousands of years old, but their distances are only thousands of light-years at most. A thousand years of time is an instant in the evolution of a star, so we need not worry about the light travel time.

Let's trace our investigation of stellar evolution to a starting point, somewhere in interstellar space. Here, hydrogen gas — making up 10 percent of the mass of the Milky Way galaxy — drifts and swirls between the stars in enormous, dust filled cloudlike structures. The study of these clouds of hydrogen gas lies entirely within the field of radio astronomy. Prior to 1951 they were unobserved; in that year radio signals from the hydrogen atoms were discovered at a wavelength of 21cm (about eight inches). By tuning a receiver hooked to a radio telescope to this wavelength, the signature of hydrogen can be easily detected.

Radio surveys of the Milky Way have revealed that hydrogen is everywhere in the galaxy. Analysis of the signals gives the distance of the gas, the shape of the clouds, their temperature, mass, and their relationship to other objects in the galaxy. The clouds range in temperature from a few degrees above absolute zero (-459 degrees Fahrenheit) to thousands of degrees above. The coldest ones are those in which much of the interstellar dust is found; it is in these clouds that star formation is likely to be taking place. But how does a nebula of hydrogen gas give birth to a star?

Imagine a gigantic cloud, hundreds of light-years in diameter — but so dispersed that you would not be aware of being inside it (assuming for a moment that we could travel there and look out a window). Over a lengthy period, as a result of pure chance, more matter gathers in one region rather than in some other region of the cloud. This small condensation tends to attract surrounding matter to it, and our original cloud of gas develops irregularities which grow in size. Eventually gravitational forces acting on such condensations will collect more matter; the subsequent increase in gravity will cause the blob to contract and grow smaller. Soon our original nebula consists of many smaller clouds of matter — many of which are physically growing smaller while all the while gathering more matter into them. Some collide with others or decompose because there is too much heat inside them to balance the effect of gravity. (Heat inside any object — whether a cloud or star — tends to cause the object to expand; gravity acts in the opposite way, causing it to grow smaller.)

Now imagine we are watching just one of these condensations in our original large cloud. As it collects more matter, it contracts further, and at the same time the atoms inside collide more often. The rate of such collisions is a measure of the temperature of the object: An increase in collisions due to an increase in the amount of gas in a given volume of space means an increase in temperature of that gas. This additional heat can be radiated away into space tending to cool the cloud; if it is not radiated away quickly then the heating will actually prevent the cloud from contracting any further. Should the condensing cloud heat up too much it will disperse.

The hydrogen clouds studied by astronomers are often well defined and fairly small (10 light-years across), and must accordingly have lost enough heat so that gravity is still in control of their further shrinkage. Radio measurements can give the temperature of — and the amount of matter in — the clouds. Therefore, we can calculate how strong the effect of gravity is and, because of its temperature, how much force is acting to disrupt the cloud. The gravitational force should be greater than the outward force produced by the heat in the cloud — otherwise the cloud would not exist. Strangely enough, this is hardly ever found to be the case.

There are virtually no clouds observed which are stable in the sense that gravity is strong enough to overwhelm the temperature effects based on the measurements that can be made at present. Is the picture suggested above all wrong? No, we do not think so. But then we do not know what the solution is either. Basically there does not appear to be enough matter in any of the hydrogen clouds in the

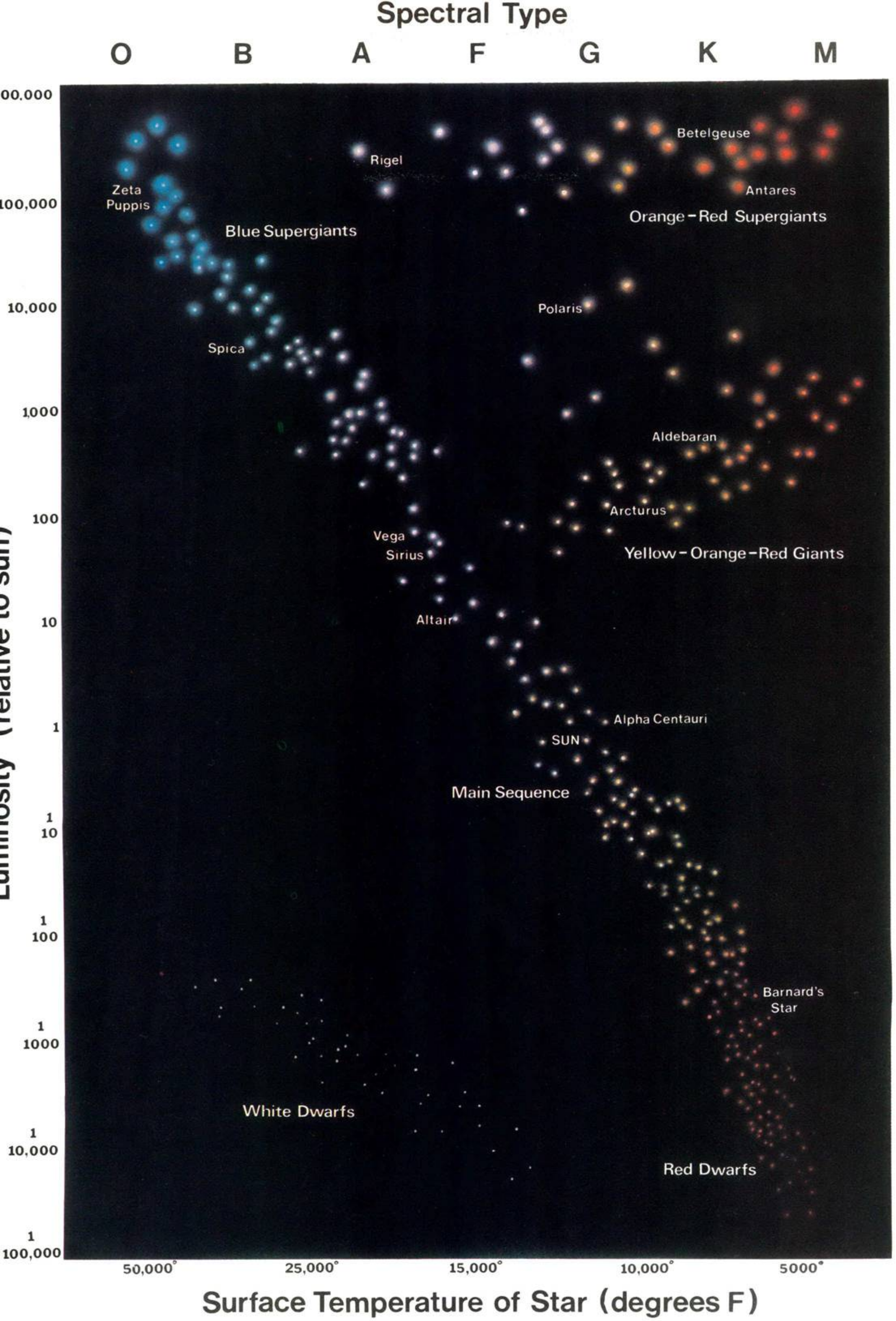
The Fate of Stars

Mass (sun=1)	Main Sequence Type	Evolution
20 to 60	O and B supergiants	nuclear burning continues to iron production, then supernova; core collapses to black hole
10 to 20	O and B giants	unstable after carbon burning; supernova; core collapses to neutron star
4 to 10	B giants	carbon burning ignites supernova; possibly no core collapse and no dense remnant
0.5 to 4	A, F, G and K solar type	never becomes hot enough to burn carbon; loses mass as planetary nebula or by other processes; degenerates to white dwarf
0.1 to 0.5	M dwarfs	never becomes hot enough to burn helium; loses mass; slow shrinkage to white dwarf
less than 0.1	black dwarf	never hot enough to start nuclear fires of hydrogen burning; only heat is from contraction and radioactive decay

Data for table adapted from computations by R.L. Sears, University of Michigan

The Hertzsprung-Russell diagram is one of astronomy's most valuable tools in understanding the evolution of stars. Each type of star can be plotted on this diagram. Temperature is the horizontal scale and luminosity the vertical scale. A few well-known stars are indicated as examples. Most stars are part of the main sequence — a zone that represents the conditions of stars during most of their lives. The more massive the star, the higher up the main sequence it spends its life. Stars off the main sequence are going through dramatic and usually relatively brief changes, or they are white dwarfs — dead stars.

Artwork by Victor Costanzo


Spectral Type
O
B
A
F
G
K
M
00,000
100,000
10,000
1000
100
10
1
1
10
1
100
1
1000
1
10,000
1
100,000
Luminosity (relative to sun)
Zeta
Puppis
Blue Supergiants
Rigel
Betelgeuse
Antares
Orange-Red Supergiants
Polaris
Spica
Aldebaran
Arcturus
Yellow-Orange-Red Giants
Vega
Sirius
Altair
Alpha Centauri
SUN
Main Sequence
Barnard's
Star
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Red Dwarfs
50,000°
25,000°
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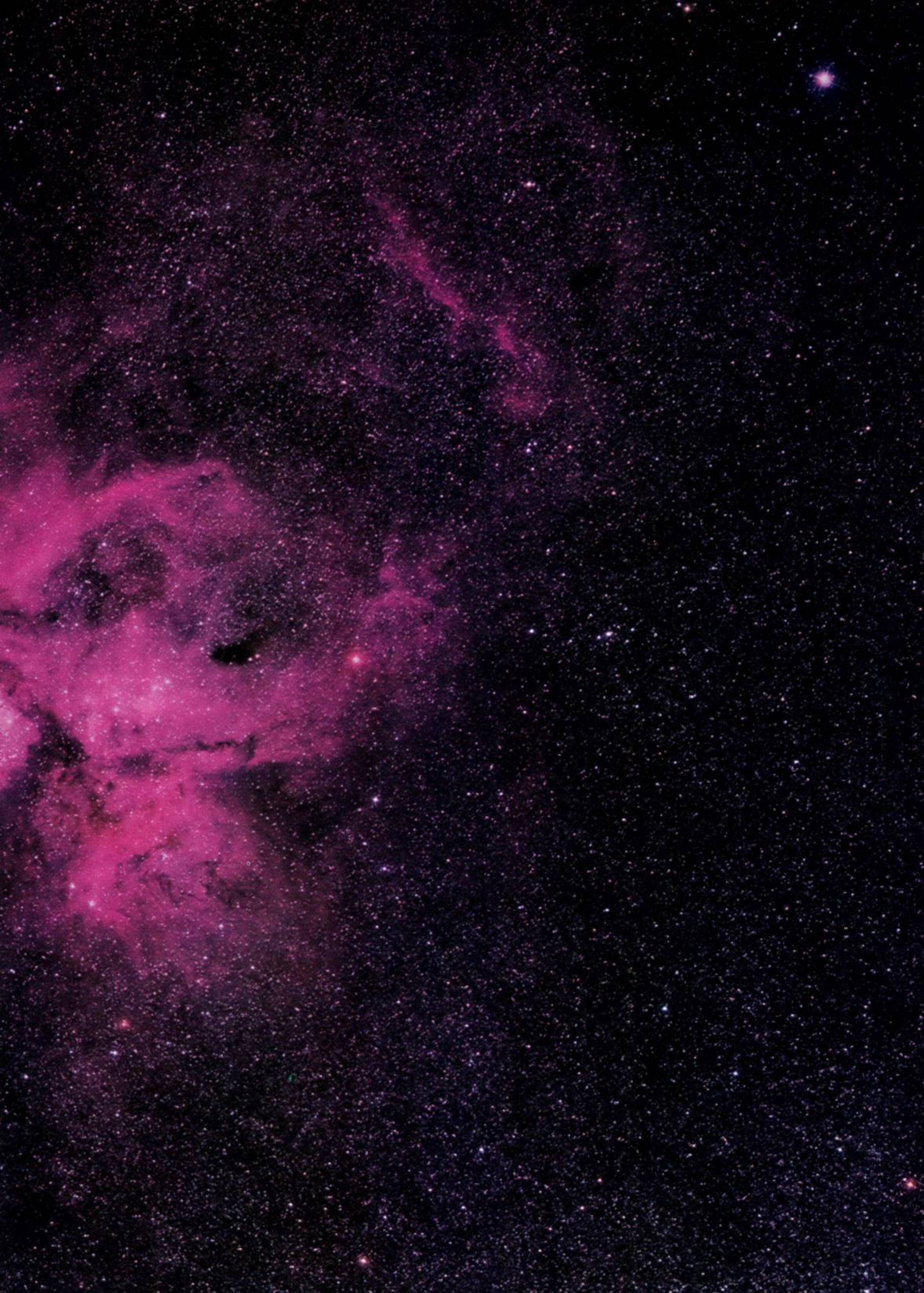
10,000°
5000°
Surface Temperature of Star (degrees F)



Milky Way which would allow them to contract and be stable. Apparently our attempt to explain the first stages in star evolution have failed. But then why are all those clouds there, and why do we see stars?

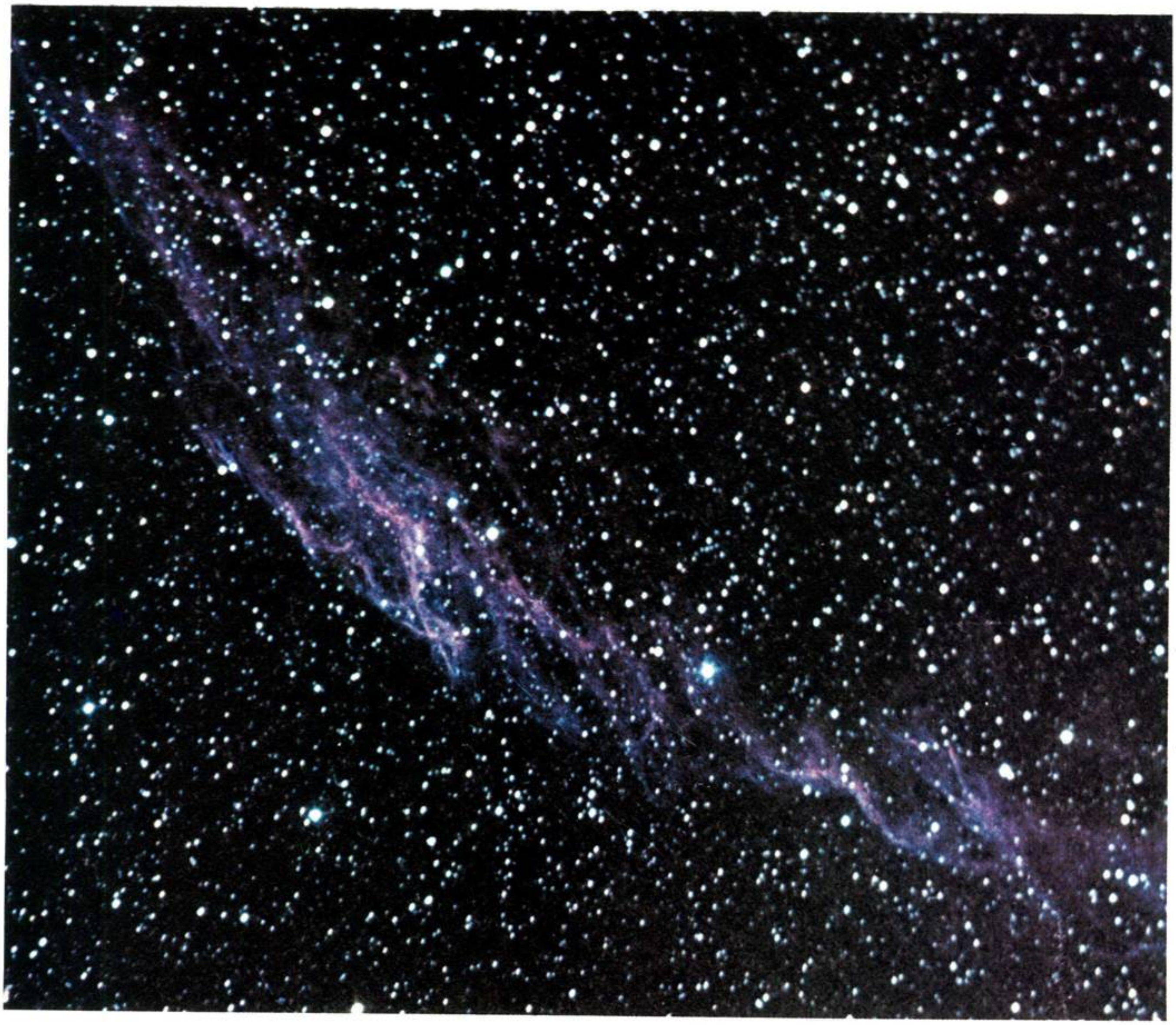
The answer requires a bit of handwaving and faith. After all, we have only been talking about the hydrogen gas in these clouds — that gas which is observed by radio telescopes at 21cm wavelength. Hydrogen is just one component of interstellar matter. We haven't included molecules, dust, black holes, and who knows what else that might exist within the clouds.

Cerro Tololo Inter-American Observatory Photograph

The Eta Carinae nebula, a great diffuse cloud 8,700 light-years away, highlights one of the Milky Way's richest regions. Within this cloud of hydrogen gas, dozens of newborn hot blue stars flood the surrounding sky with energy, illuminating the nebula in the process.

Basically, the dust and the molecules in the clouds are now known to be an insignificant fraction of the cloud's mass, and do not help to increase the gravitational pull of the cloud. Fortunately, however, there is one component of matter which we find very hard to observe and which is expected to exist in these clouds — molecular hydrogen. This molecule (two hydrogen atoms stuck together) has so far only been observed in the direction of a few stars by means of ultraviolet telescopes; we really do not yet know how much molecular hydrogen lies in typical atomic hydrogen clouds. Such a situation is tailor made for any theoretician to work with because there is no data that could contradict any assumption that is made about the amount of additional matter in the clouds.

While it appears that no hydrogen clouds could possibly exist because they do not contain enough



Photograph by Orien Ernest

Like a streamer of smoke from a snuffed-out candle, the Veil nebula threads across light-years of space as the ghostly remnant of an exploded star. Apparently the Veil is being illuminated by energy from an as-yet-undiscovered hot star. The nebula's gas and dust, enriched with heavy elements, may someday be drawn into the formation of new stars and planets.

hydrogen to produce the necessary gravitational pull, we must conclude that there probably is enough additional molecular hydrogen present which we have not yet found. If you want to be more daring, you might conjure up some black holes to account for the missing mass. This whole missing mass problem is one that is found in many areas of astronomy, not just in hydrogen clouds. Many star clusters and clusters of galaxies also do not contain enough matter to prevent them from expanding outward so they too should quickly cease to exist.

To get back to our cloud of contracting gas, we assume it must have enough matter to cause it to contract. In the meantime, it radiates away the heat that is generated as a result of contraction. Now, however, we find that many of the densest clouds (which are also the coolest ones) contain dust particles and complex molecules. Neither the origin of the dust nor the processes of molecule formation are yet totally understood. What we do know is that some of the molecules like CO (carbon monoxide) are very efficient radiators of heat, and their existence will speed up the cooling down of the cloud. This means that the cloud in which CO exists might contract fairly quickly because it rapidly loses its heat.

But this use of CO now presents a difficulty. The molecules observed in these dense clouds do indeed contain heavy atoms such as carbon and oxygen (as in CO). But these atoms had to be made in stars in the first place. Now we are saying that clouds contract to form stars because they cool down with the help of some good radiators, in the form of CO and other molecules. In that case, how did the first generation of stars — those born before there was much matter in the universe other than hydrogen gas — get formed? There was originally nothing to help cool the clouds down. Is it possible that some of the heavier atoms were made in the *big bang* that started it all off here in our universe? Astronomers don't think so. Then is it possible that the first generations of stars were formed much more slowly, relying on eddies of gas to concentrate the matter? Perhaps. But whatever the case, star formation early in the life of the galaxy was likely very different from the way it is now.

Setting this problem aside we will get back to our cloud, now rapidly cooling so that — while it might have taken billions of years to reach the molecule phase — it might only take millions of years to collapse into a star. In the last stages of collapse matter falls freely into the center of the cloud.

As the cloud gets smaller and smaller, subunits within it might individually form smaller blobs which will contract independently of the others. This would depend on how much matter they contain and how fast they can lose their heat. However, we now reach an important step. The small cloudlets become so dense that the dust within them starts to act as a shield which prevents the heat from escaping. That means that the center of the small contracting blob will heat up. If conditions are just right, the heating might come too late to play any role in stopping further contraction — and the cloudlet (now comparatively small but still much larger than the solar system) will get hotter as it continues to shrink. When it reaches a temperature of 1,000 degrees or so above absolute zero, it will radiate so much heat that it is best observable from Earth as an infrared source. This new phase is called a *protostar.*

The process continues — the object getting hotter and smaller — until at some time the temperature at the core reaches 30 million degrees.

At this temperature, nuclear reactions — which "burn" the hydrogen to form helium — begin. Then, as if to resist any further evolution, the star starts to oscillate wildly in brightness for a few thousand years. Only when it has settled down as a relatively steady nuclear burner can it rightly be called a star.

One of the problems in understanding how we get from a cloud of gas to a star concerns the rotation of the cloud itself. Any cloud will have a small amount of rotational motion in it. If the cloud contracts, the laws of physics say that it should spin faster. This is the well-known effect that allows a skater to spin faster when she pulls in her arms while spinning on the ice.

The simplest calculations for star formation suggest that all stars should be spinning very, very fast as a result of their enormous contraction from cloud to star — but they do not do so. Why not? The answer is far from known at present, but several possibilities exist. In order to avoid this spin-up, the star must rid itself of material. Various mechanisms might operate to facilitate this. For example, as the young star is getting hotter and hotter it might cause much of the surface material to be blown away due to the enormous heat being generated. This would allow the star to slow down its spin by carrying off the momentum in this stellar wind. Alternatively, the high spin might cause a disk of matter to be drawn out from the star — a disk that might ultimately form planets. Whatever the method whereby the star loses its spin, stars *do* form and they *do not* spin themselves into instability.

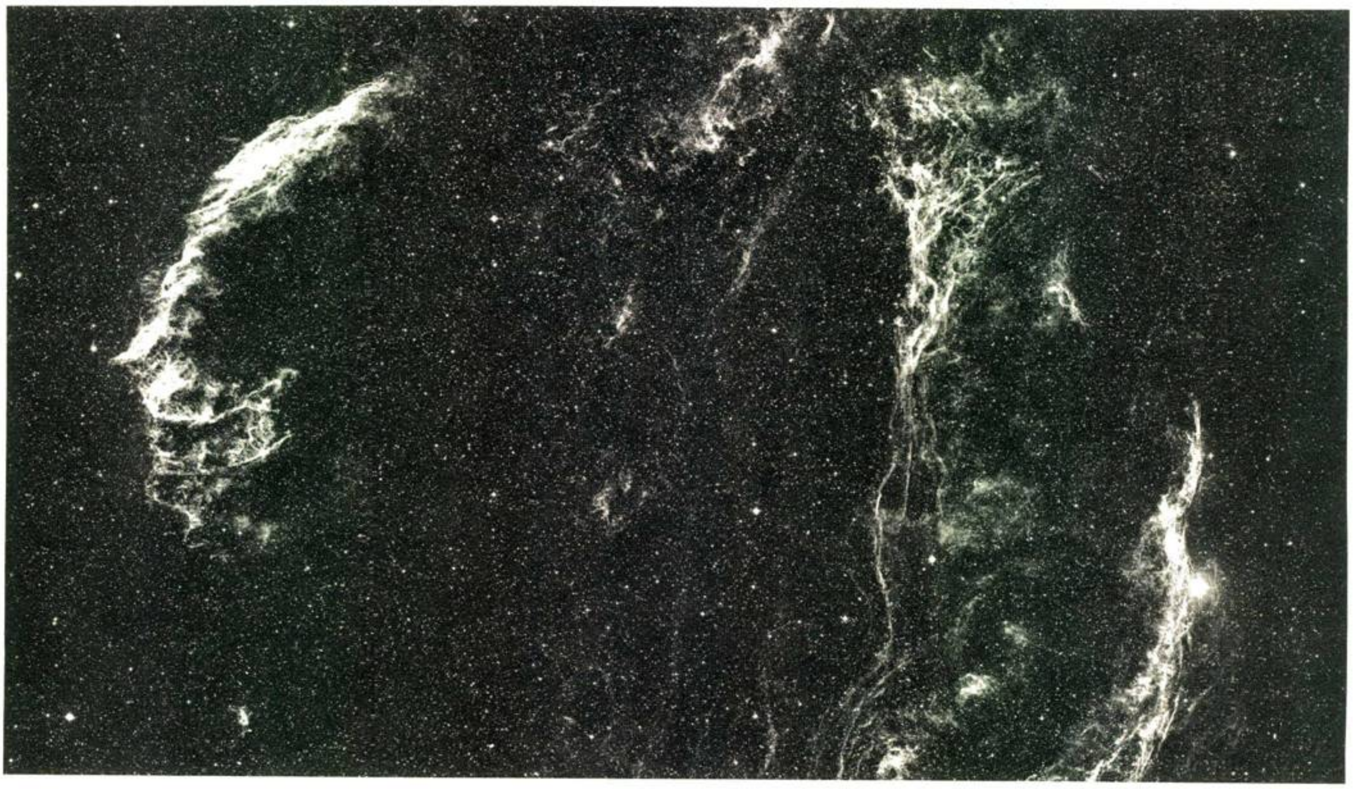
Another effect that acts to stop a cloud contracting to the size of a star concerns magnetic fields in space (see "Magnetic Fields Beyond Earth", March 1974). These fields are everywhere in the Milky Way and they control the motions of hydrogen clouds and possibly their shapes and sizes as well. Although hydrogen gas finds it very hard to move across magnetic field lines, it can easily flow along them. This means that if a cloud of gas is contracting to form a star, and there is a field present, the contraction is inhibited across the field but can occur freely along the field. This would imply that the cloud would develop an elongated shape which is at right angles to the field lines. In my own research, I have found that this is not so and that most hydrogen clouds are elongated along the field lines! This makes nonsense of what was said above, but here again we are far from understanding all the details of how clouds actually become stars; this is one more detail that still needs to be worked out.

A more worrysome detail is that the magnetic field in a cloud increases as the cloud contracts. The field lines actually "stick" to the hydrogen gas; as you bring the gas closer together the field gets stronger. From observations of magnetic fields in clouds of different densities, we can predict that by the time the gas has contracted to become a star, the field should be millions of times stronger than the fields actually observed in stars. Somehow the field leaked away into space — otherwise the star simply could not have contracted. No one really understands how the fields leak out of the protostar. Once again a detailed explanation is still needed.

Returning to our story...we had a cloud that contracted and became the size of the solar system. It started to heat up and at some critical time — when the internal temperatures were several million degrees — the star itself started to shine. Can we be sure that any of this is correct in view of the problems mentioned above? The answer is that we probably can, since we do actually see objects which appear to be at various points along the evolutionary track. We see the gas clouds and we see very dense, compact dust clouds called *globules*. These globules are so dense that no light penetrates them. However, radio signals do and these signals show many complex molecules inside some of the densest dust clouds. In addition, some of the dust clouds contain infrared objects which are thought to be the protostars themselves. These protostars have not yet heated up to stellar temperatures, and are only several thousand degrees at most — some are as cool as +600 degrees Fahrenheit. Their radiation is primarily in the infrared part of the spectrum and they are observed in and around many emission nebulae — mostly inside dust clouds. Good examples are the infrared stars behind the Orion nebula.

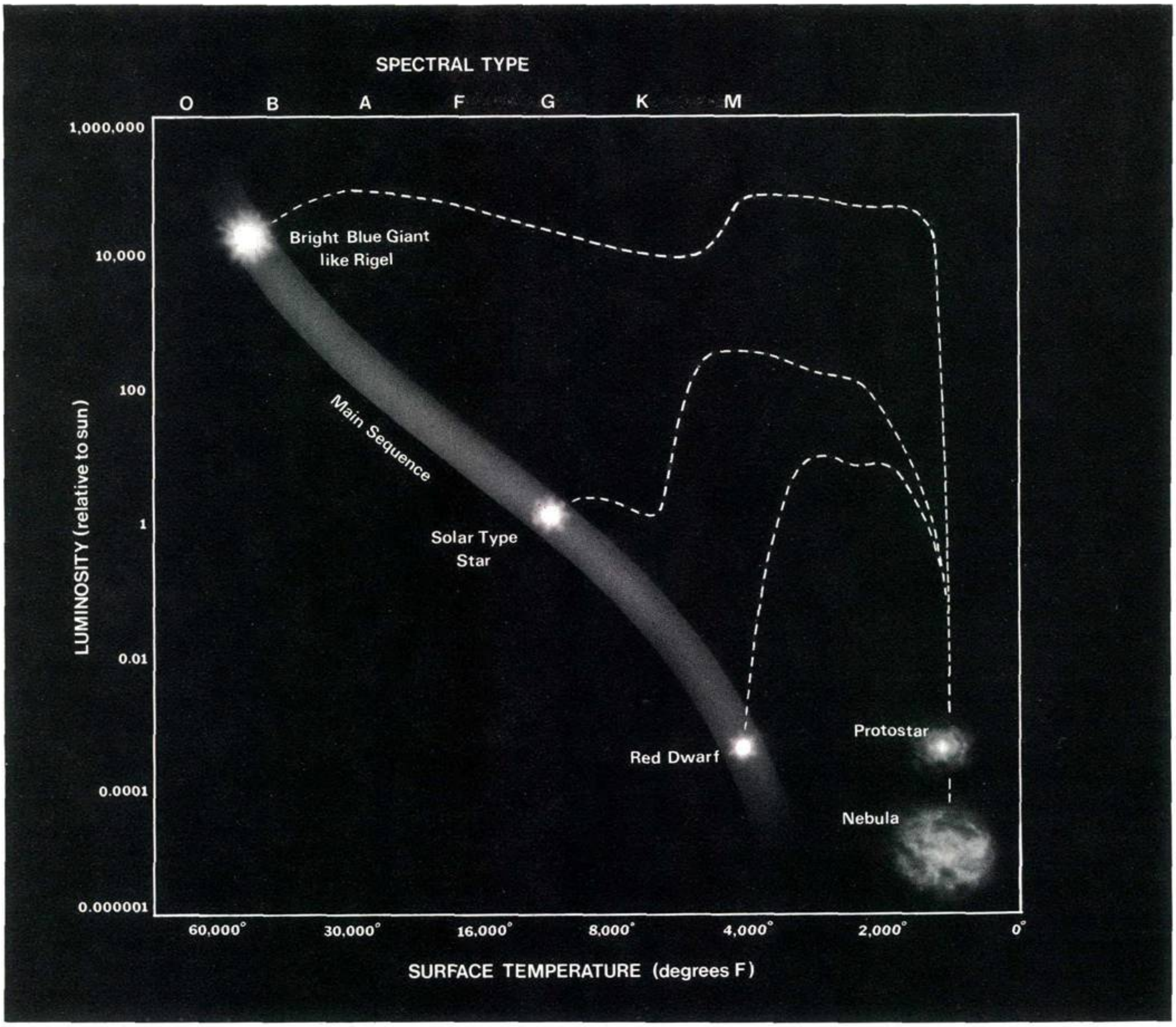
In some dust clouds, the dust is so thick that even the infrared radiation cannot escape — but radio signals can still penetrate. In these cases, the radio emission from the OH (hydroxyl) molecule within the clouds is extremely strong and the intensity can only be explained if there is amplification of the signal in the cloud itself. The theories that best explain this amplification (by the maser process) require the existence of strong infrared radiators such as the protostars that we believe are obscured from our vision.

When the star first starts to shine, the heat will drive the dust and gas cloud outward and destroy much of the complex material in the cloud. The star (or stars) burn a hole in the cloud so that they suddenly become visible, as if a curtain has been pulled open. Such stars have in fact been seen to appear.



Mount Wilson and Palomar Observatories Photograph

The fragile looking Veil nebula represents the scattering debris of a dead star. Estimates place the star's supernova explosion at 30,000 to 40,000 B.C. For thousands of years following, the Veil nebula retained a much more circular shape as its gas shell expanded away from the blast at hundreds of miles per second. Resistance from interstellar gas and dust has slowed down and fragmented the nebula into the presently tenuous appearance. A close-up view appears on page 14.



Artwork by Victor Costanzo

All stars condense from vast clouds of dust and gas. The mass of the star so formed determines its destiny as a main sequence star, and later its demise. From a plot of evolutionary tracks on this temperature-luminosity diagram, massive stars remain about the same brightness as they develop from protostar to main sequence — the only change being temperature. The sun and less massive stars were much more luminous during their early phases.

During this century, at least two new stars (FU Orionis and V-1057 Cygni) were discovered where none was visible before. In both cases the stars were associated with small dust clouds.

After the star starts to shine, it is what we call a *T-Tauri* star — an irregular variable star which appears to be fighting the fact that it must soon start to shine with a steady glow. It seems certain that this oscillating stage is the one just prior to what is considered a normal star. T-Tauri stars always are embedded in nebular material where star formation is believed to be occurring. They appear to be either ejecting a lot of matter or spinning very rapidly. In either case, they are probably going to lose material in sufficient quantities so that they will ultimately be able to rotate more slowly as a normal star.

Just what is a normal star?

Stars do not come in random sizes, temperatures and brightnesses. There are certain limits, and all stars seem to fall within them. The discovery that the stars are nicely organized in this way was made early in this century by the astronomers Hertzsprung and Russell. They measured the effective temperatures of many stars (found from spectroscopic examination of their light) as well as their actual luminosities (for which distance information was needed). They found that if these properties are plotted on a graph (now called the *Hertzsprung-Russell* or *H-R diagram*), most stars fall along a clearly defined zone. This zone on the graph is known as the *main sequence*. Most stars in the galaxy, including our sun, are known to be main sequence stars.

Computer models of the evolution of stars have

The Cone nebula in the constellation Monoceros resembles a celestial Mount Olympus, stretching six light-years from base to peak. Above the nebula are many superhot O and B type stars predominating star cluster NGC-2264. The Cone nebula indicates that stars are still being born within one of the youngest clusters known.

Hale Observatories Photograph

been able to account for the presence of the main sequence stars and also for the way the stars evolve onto and off the main sequence. Since most of the stars in the galaxy lie on the main sequence, we can conclude that most stars spend most of their lives as main sequence objects. Those stars that lie off the main sequence are all fascinating objects in their own right. The T-Tauri stars are located just off the main sequence, but as they evolve toward normalcy their temperature and luminosity changes so that they "move" onto the main sequence.

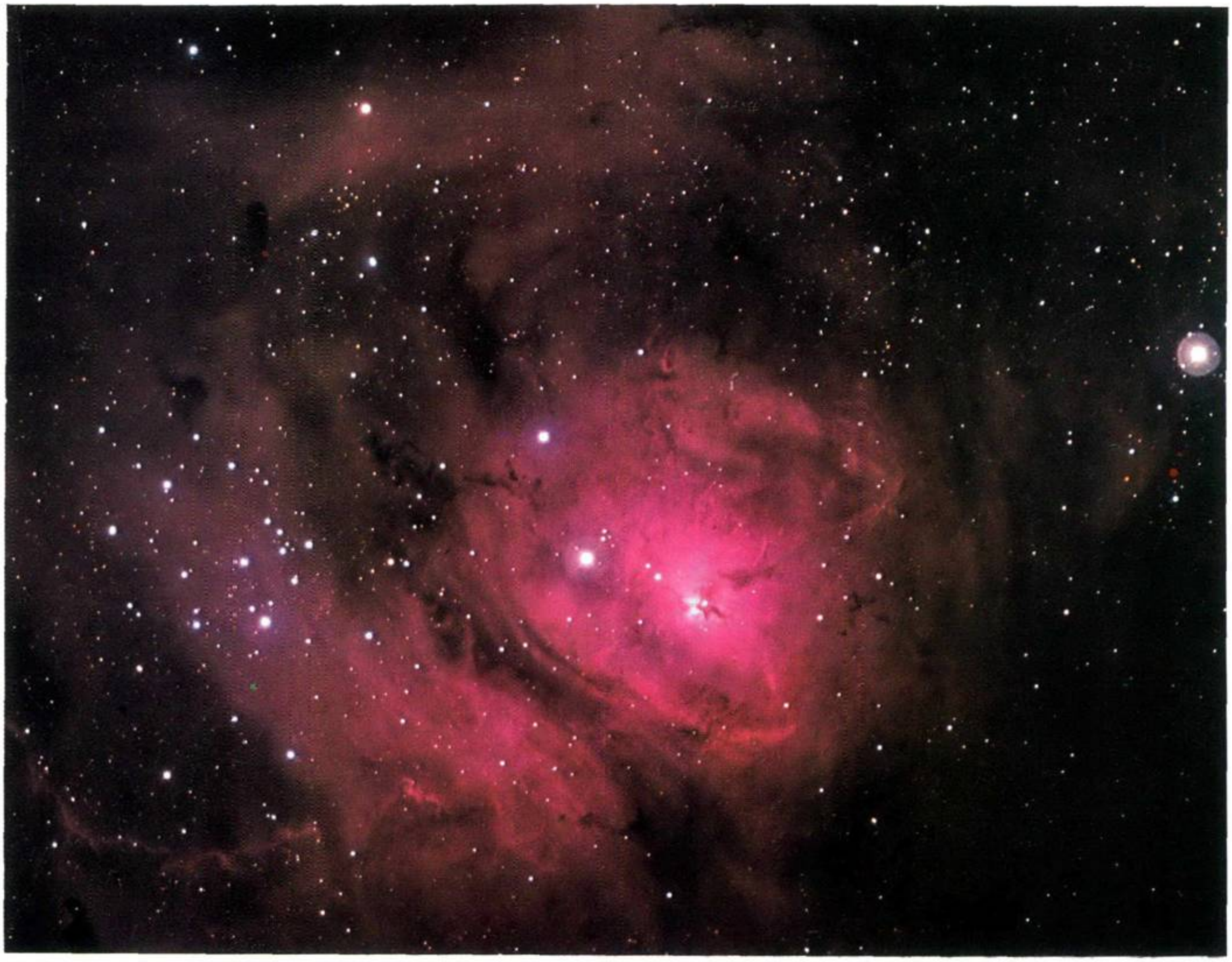
For billions of years, the star shines steadily as a main sequence star. A star spends most of its life near a specific point on the main sequence because its basic properties remain largely unchanged. However, later in life its luminosity and temperature change as does its position on the H-R diagram, and it ceases to be a normal main sequence star. At this transition period, most of the hydrogen at the center of the star is converted to helium. Now nuclear burning continues in a shell around this core. The fire in the core effectively dies out. However, this means that the core — being cooler — will contract, which in turn means that it will again heat up. Now it gets so hot that the nuclear burning in the shell is accelerated. To a distant observer the star appears to be much increased in brightness at this point.

The other consequence of these changes is a ballooning in size. Because the amount of energy emitted by the star does not increase in proportion to its increase in size, the surface temperature drops and it changes color from yellow (for a solar type star) to red. The star becomes what is known as a *red giant* — radiating hundreds of times more light than when it was a normal star.

According to computer calculations, the red giant's core reaches a temperature of 100 million degrees, igniting the helium and forming heavier elements such as carbon. The core of the star is now a nearly solid blob of matter (no longer a gas). The sudden heating produced by the burning helium happens so fast (a few hours) that a minor explosion erupts (minor by comparison to some other explosions a star can undergo). Most of the energy from this explosion is absorbed in the outer layers of the star which are still burning hydrogen.

After the helium burning explosion (called the *helium flash*), the core of the star cools down and, as a consequence, the whole star cools down and once again starts to contract. Its life as a red giant is

Two well-known nebulae graphically display star birth and death. In the pinkish Lagoon nebula is a drapery of hydrogen gas stretching across 50 light-years of space. Knots of condensing gas and dust imparting a marblelike texture to this emission nebula identify regions where dozens of stars are slowly condensing. An explosion seemingly frozen in space identifies the Crab nebula (below). Its tortured, twisted structure does indeed mark the location of an explosion — a supernova — that occurred over 900 years ago. At the center of this expanding cloud, the supercondensed ashes of the event exist as a neutron star or pulsar.



Kitt Peak National Observatory Photograph

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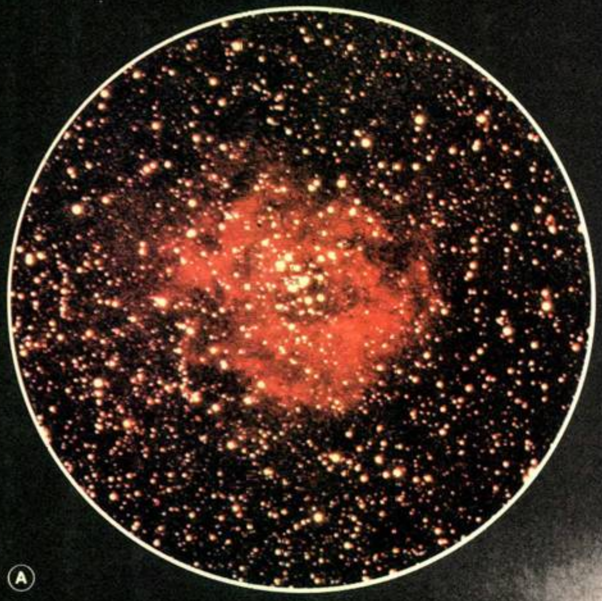
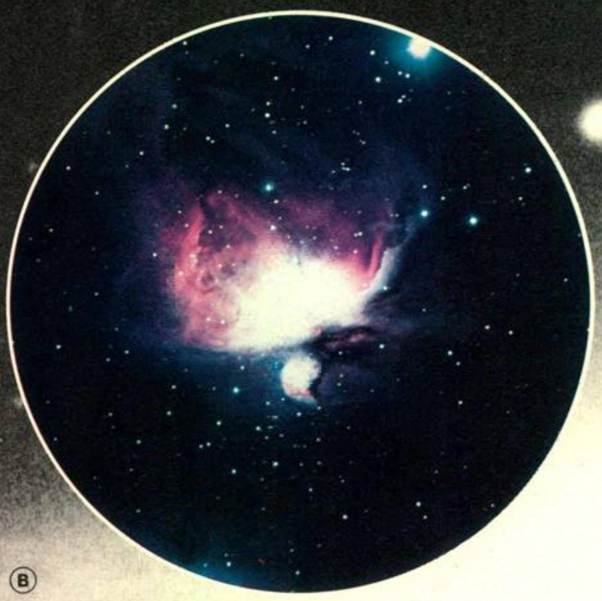
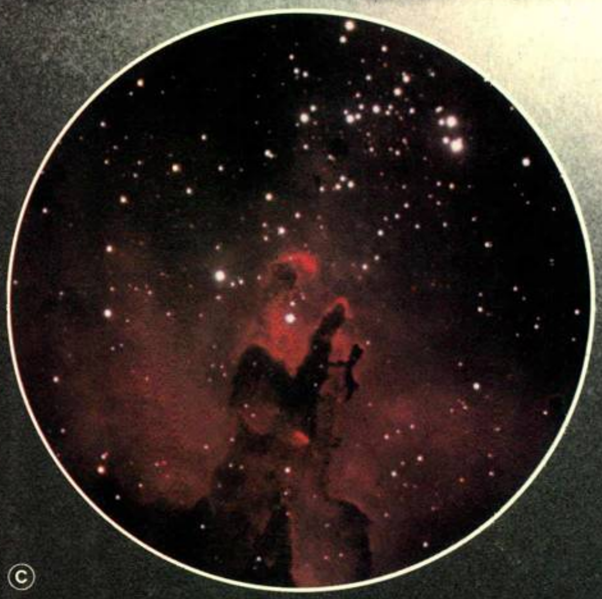




over. By contracting for the next 10,000 years, the center gets hotter all over again and the temperature gets high enough to trigger further helium burning. Now, however, there is no explosion in the core — and the star gets most of its energy from the burning helium. It continues to do this in a stable manner, although the hydrogen-burning shell is now running out of hydrogen and the helium burning in the core is spreading throughout the star. This leaves carbon (the "ash" from helium burning) as the main constituent at the center of the star. The helium, in turn, now starts to burn in a shell around the carbon core. The same effects that happened before start once again. The core of the star stops burning helium; it cools, contracts, heats up again, and tries to explode — but this time the process is more complicated. The star starts expanding toward another red giant phase but does so very rapidly (taking a few million years this time compared with hundreds of millions of years the first time). We are now reaching the last stages of the star's life.

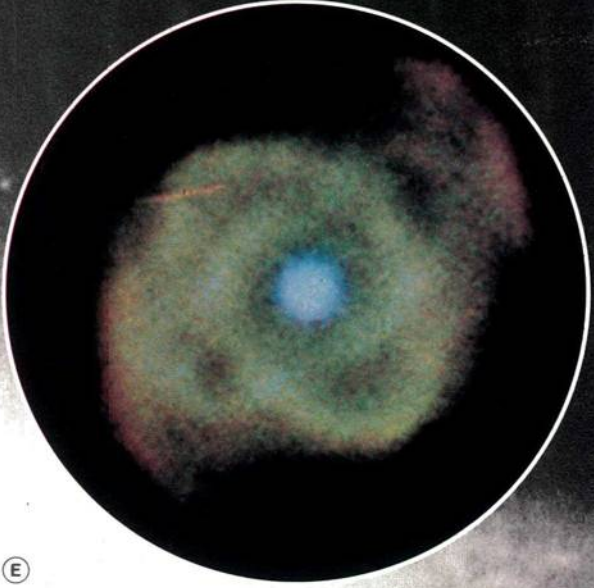
At this stage different stars suffer different deaths. Many will not reach this second red giant phase at all. Many will die in explosive events — some gentle, others totally catastrophic to the stars and all living things within tens of light-years of the explosion. Let us consider the fate of the various types of stars.

The smallest stars — less than 1/2 the sun's mass — might never become hot enough at the center to trigger the helium or carbon burning phases. They simply pass quietly away, fading out and eventually becoming cold dark objects called *black dwarfs*. Others like the sun — or perhaps twice as large — undergo another end. For these stars, the enormous amounts of heat being generated in the core near the end of the star's life have difficulty escaping and become absorbed into the outer layers of the star which, in turn, get pushed outward. If conditions are right, this outer shell continues to expand out into space for thousands of years. From



Emission and planetary nebulae are stellar evolution in action, painting dramatic portraits of star birth and death. The emission nebulae on page 20 are huge celestial incubators where batches of hundreds to thousands of stars are slowly condensing from interstellar dust and gas. Each nebula shines by ultraviolet energy emitted from energetic newborn stars embedded within. The donutlike planetary nebulae on page 21 mark the death

A) Rosette nebula, photograph by John Sanford
B) Orion nebula, photograph by Orien A. Ernest
C) Eagle nebula, Kitt Peak National Observatory photograph



E

F

D

a distance the star seems to be surrounded by a cloud of smoke. The Ring nebula in Lyra is such an object.

The shell of the star that becomes a so-called *planetary nebula* is cool, but the regions just under this shell are much hotter (100,000 degrees as compared to 4,000 degrees). As the shell expands away, the inner parts of the star are revealed and we find a hot star where there was a cool one before. The central star of the planetary nebula has in fact been stripped naked of its outer layer of gas. Decline now sets in as the star is running out of fuel. The central regions cool and gravity takes control — compressing the star to about the size of Earth. At this size, the crushing force of gravitational collapse is finally stopped by the outward pressure of highly compressed atoms. The star is now a *white dwarf*, with every cubic inch containing 10 tons of matter. At an agonizingly slow rate the white dwarf radiates its last energy into space for millions of years. Finally its storehouse of gravitational energy is exhausted and it ceases to shine, becoming a black dwarf.

More dramatic — and very relevant to the existence of the planet Earth as we know it — is the death of a larger star (say about 10 times the mass of the sun). The interior of such a star also collapses, but now there is so much matter falling inward that the core heats up to an incredible 600 million degrees. At this temperature, carbon — the end product in a solar sized star — is consumed by nuclear processes, forming magnesium and other heavier elements. The collapse is temporarily stopped while the carbon is burning (because of the outward pressure of its heat), but finally even the carbon is used up.

Once again, the core runs out of fuel (carbon in this case) — so the heat generation stops and the collapse resumes. The temperature now increases even more as other elements are cooked up in the nuclear furnace. But when iron starts to be formed, a critical step is reached. Now conditions are suddenly very different. Instead of generating heat in the process of making iron (as it has in producing

throes of stars nearing the ends of their lifetimes. For still unclear reasons, some stars eject their outer shells of gas, and this rapidly expanding hot material appears as planetary nebulae. They are one of the universe's primary means of recycling matter. After interference by the interstellar medium breaks up planetary nebulae, their chemical constituents are fed back into the galaxy for building new stars and solar systems.

D) Helix nebula, photograph by Orien A. Ernest

E) NGC-6543, Lick Observatory photograph

F) Ring nebula, Kitt Peak National Observatory photograph

all the elements up to this point), the star has to use its available heat supply in transforming the lighter elements into iron. Suddenly, within only hours, the center of the star cools down; all the available heat is swallowed in the sudden production of iron. The fire in the star's center literally goes out as if suddenly extinguished, and the core collapses catastrophically.

The outer shell of the star — still merrily burning away and making heavy elements — suddenly has little below it to help hold it up against the forces of gravity. The shell promptly plunges in toward the iron core. The implosion is rapidly followed by an explosion, because the shell bounces back from this collapse (much like a spring), and it is thrown out from the star at 5,000 miles per second. The shell travels ever outward, propelled by the enormous flash of energy. Meanwhile the core collapse generates even more heat that ignites the outer parts of the expanding shell to enormous temperatures. The exploding star now shines with the light of a billion suns and can be seen from neighboring galaxies.

If such an explosion occurred close enough to Earth (perhaps 3,000 light-years away), it could be seen in the daytime. This stellar suicide is called a *supernova*. One supernova is expected to occur in the Milky Way galaxy every 50 to 100 years.

All the heavy elements created in this incredible sequence of events are spewed into space. Ultimately other stars form in clouds of recycled material — recycled to space by the supernovae. Planets form again, this time made of a mixture of heavy elements built in the death throes of millions of stars, eons ago. These same heavy elements are in each of the complex molecules in our bodies and in all living organisms on this planet. We are literally children of the stars.

But the story is not over yet. What happens to the core of the star that exploded — the central parts left after the shell blew off so castastrophically? In the most bizarre of all the sequences, the core continues to rapidly collapse until there is so much compressed matter that the forces between the electrons (which prevented further contraction in the white dwarf) are completely overcome. The star continues to get denser and denser. Electrons and protons are forced so close together that they combine to form neutrons. The star is now neither gaseous nor solid, but consists entirely of neutrons. Matter as we are used to imagining it no longer exists in this object.

The former stellar core has become a *neutron star* or *pulsar*. Pulsars spin rapidly — many times a second — and their spin is actually the source of more energy which can be fed into the surrounding remains of the supernova explosion. From these supernova remains, fed by the pulsar, streams of deadly cosmic rays are sent into space. (See "Why Does the Crab Nebula Shine?", January 1975.) These neutron stars or pulsars radiate pulses of light, radio and X-ray emissions, and are detected on Earth by astronomers using telescopes operating in these parts of the spectrum.

Sometimes the neutron star — a 10 or 20 mile ball of neutrons — is not the final destiny of the star. If the star that originally exploded was more than about 20 times the sun's mass, then the collapse of its core does not stop at the neutron star phase. Even the forces keeping the neutrons apart are overcome by the all-pervading force of gravity. A point is reached where nothing — not even light — can escape from the object; at this point we call it a *black hole*. A stellar collapse black hole has a diameter of only a few miles when it disappears from sight. But down inside the hole the matter it contains continues to shrink forever, reaching a size so small that we cannot even conceive of it in any physically meaningful way. Now only mathematics can describe the object.

These stages of evolution of stars from beginning to end are just as inevitable as those that affect our lives. Just like us, stars are born and must ultimately die to give way to the next generation. Stars created out of cosmic clouds of gas and dust usually have very long lives, but all must die when their fuel runs out. Some go quietly, others with an incredibly destructive explosion. Life on any planets orbiting stars that reach the end of their lives will also cease. There is no escape from that.

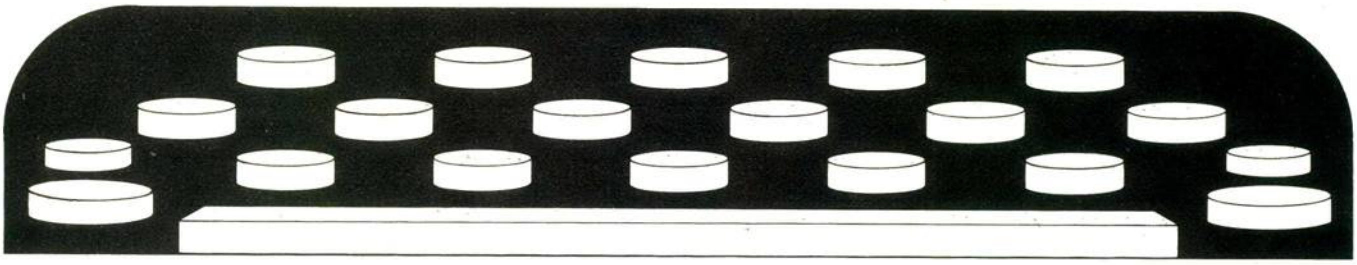
For Earth and our sun, that time is still billions of years in the future. What is more likely to destroy us is a circumstance where Earth will be too near some other exploding supernova. If any living things survive, the struggle for survival will virtually start from point zero again.

The galaxy around us is probably full of dead stars — black dwarfs, white dwarfs, neutron stars and black holes. Most of the discoveries of these objects were made only in the last 10 years, and the picture of the evolution of stars as outlined here is not much older. Who knows what new chapters in this saga will be unveiled in years to come as astronomers continue their search into the secrets of the cosmos.

This recent photograph of radio galaxy Centaurus A (NGC-5128) reveals, for the first time, star birth occurring 16 million light-years away on that island universe. Filaments of dust and gas are silhouetted in front of red glowing material apparently being energized by hot young stars buried within it. Centaurus A ranks as one of the most mysterious extragalactic objects ever observed. Its unusual appearance suggests that the galaxy is exploding at the center.

Cerro Tololo Inter-American Observatory Photograph

Dr. Verschuur is a regular contributor to ASTRONOMY. He is director of the Fiske Planetarium and a professor in the department of astrogeophysics, both at the University of Colorado in Boulder. In addition to over 50 published scientific articles, he has contributed "The Interstellar Medium" to the 1973-74 edition of **Encyclopaedia Brittanica** *and is author of* **The Invisible Universe** *(Springer-Verlag, New York, 1974), a layman's introduction to radio astronomy.*



IN FOCUS

Sir / The unusual motion of an unidentified object reported by Robert Purdy (December 1974) — which at first seemed to be a satellite until it "abruptly stopped and reversed its motion" in the vicinity of Alderamin (Alpha Cephei) — suggests the *possibility* that the object may have been a Russian Molniya communications satellite whose unusual orbit results in such a ground track.

The Molniya are launched into a highly elliptical orbit which typically has an apogee of approximately 25,000 miles, a perigee of about 300 miles, and an inclination of 65 degrees — giving the spacecraft an orbital period of approximately 12 hours. One of the two daily apogees occurs when the satellite is over the USSR; the other is over North America.

At the time of Purdy's sighting, there were nearly 20 Molniya satellites in orbit. (Not all of them were still functioning.) Each Molniya carries six large solar-cell panels that unfold in orbit, giving the giant spacecraft an effective diameter of roughly 30 feet in terms of reflecting surface for sunlight. In recent years, the United States Air Force has launched two experimental military communications satellites into Molniya type orbits, each believed equipped with a very large parabolic antenna.

Whether one of the many Molniya satellites or the two USAF spacecraft could provide a first magnitude brightness from a distance of 25,000 miles, as Purdy estimates, is a moot point. But the coincidence of the reported motion and inclination of the unknown object with the Molniya orbit ground track suggests that one of the Russian or USAF satellites might have been responsible.

The Russians selected this unusual orbit — in preference to the equatorial "geosynchronous" orbit used for most U.S. communications satellites — for several reasons. One is that the location of existing Soviet launch sites is not convenient for achieving equatorial orbit except by seriously sacrificing satellite payload. Another is that the unusual Molniya orbit provides better coverage of higher latitude regions in the USSR than an equatorial orbit.

The enclosed Molniya orbit ground track chart shows that satellites can *appear* to Earth based observers to stop and reverse direction.

PHILIP J. KLASS
Washington, D.C.

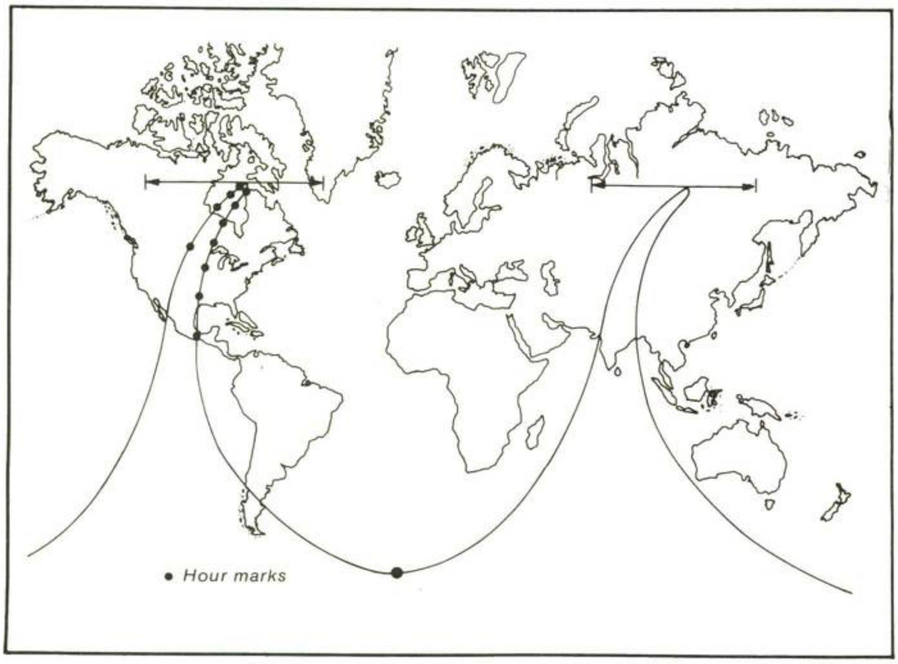
Sir / In reading through Eric Burgess' article on interstellar flight (March 1975), there is an error in the description of perturbations in the perception of time at near-light speeds. Burgess correctly points out that, as observed from Earth, the ship's crew would appear to be slowed in time. However, his subsequent point concerning the apparent speeded-up activity on Earth if observed by the space travelers, is in error.

A very important concept in relativistic theory states that all motion is relative; there is no fixed reference point in the universe to measure "proper motion" against. Due to this fact, the crew cannot distinguish whether *they* are moving from Earth, or Earth away from them. Empirically from this we can see that any observations thus made by the crew must be of the same nature as ones of the crew from Earth. In other words, the crew would also see events on Earth slowed down relative to themselves. Although this would seem to be a contradiction, it follows directly from the famous time-dilation equations.

Otherwise, I found the story very interesting in its speculations. In general, I greatly enjoy ASTRONOMY in all its aspects.

JOSEPH D. SACCO
Brookline, Mass.

Mr. Sacco / You are quite correct. This error snuck in during our editing and was not a misconception by Burgess.



A typical 12 hour orbit of a Soviet Molniya communications satellite consists of a strange double loop as explained in the accompanying letter. This satellite family's direction reversal over North America may be the explanation for UFO sightings reported here in earlier issues.

Letters intended for this column should be addressed to The Editors of ASTRONOMY. We are sorry but the volume of mail does not permit individual replies.

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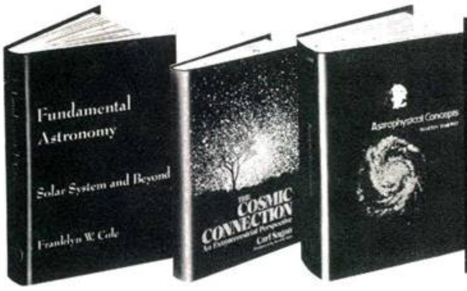

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The Changing Surface of Mars

by
Joseph Veverka,
Carl Sagan, Lynn Quam,
Robert Tucker, Botand Eross

The solar system would be a much less interesting place without Mars. In contrast to the stark, frozen faces of the moon and Mercury, or the eternally cloud-veiled Venus and giant planets, Mars is a world of constant changes. These are changes which to some extent we can identify with on our own restless planet: the periodic shrinking of the Martian polar caps, clouds, dust storms, and mysteriously seasonal variations in dark surface features. Indeed, Mars is the only planet that we can even endow with winter and summer seasons.

Although popular theories have suggested that many transitions on the red planet are related to meteorology, planetary scientists had to wait until the Mariner 9 space probe provided detailed glimpses of the Martian weather machine at work. Unlike previous Mariners that flew by Mars in the 1960s, this spacecraft *orbited* the planet and sent back pictures for almost a year. This allowed planetary scientists for the first time to receive close-up images of the same areas, taken weeks apart. Since that spectacular 1971 mission, Cornell University's Laboratory for Planetary Studies has been using a new computer picture comparison technique (developed at Stanford's Artificial Intelligence Laboratory) to look for changes on Mars.

One of the most intriguing results gives a detailed view of the so-called *seasonal darkening* phenomenon. Early theories attributed the apparent seasonal darkening of surface features to the most obvious Earth analogy — the annual growth and decay of vegetation. This belief was boosted by the fact that the melting of one of the polar caps accompanied the darkening in that hemisphere, suggesting that water was being pumped back into the atmosphere for Martian vegetation to sprout.

When more recent observations found the Martian atmosphere too dry and thin for this kind of cycle to occur, new theories explained the darkening as the shifting of dark or light surface material by high winds. Like on Earth, these prevailing wind patterns should vary with the seasons — setting up a different but recurring pattern of light and dark markings.

Mariner 9 photographs confirm this hypothesis and give a detailed view of the mechanisms at work. Ironically, when Mariner 9's braking rockets first placed it in Martian orbit in November 1971, absolutely no dark areas could be detected. The entire planet was bathed in a historically unprecedented global dust storm. As the storm subsided, Mariner 9 photographically revealed a gradual darkening of many classical dark areas. In the case of Syrtis Major (a very prominent feature near the equator), this darkening resulted largely from the development of many crater-associated *dark streaks* or *tails* as shown in picture 3. Just as a field of black and white dots blend into shades of gray in a newspaper photo, some of the dark Martian areas break up into a mosaic of dark streaks when viewed close-up.

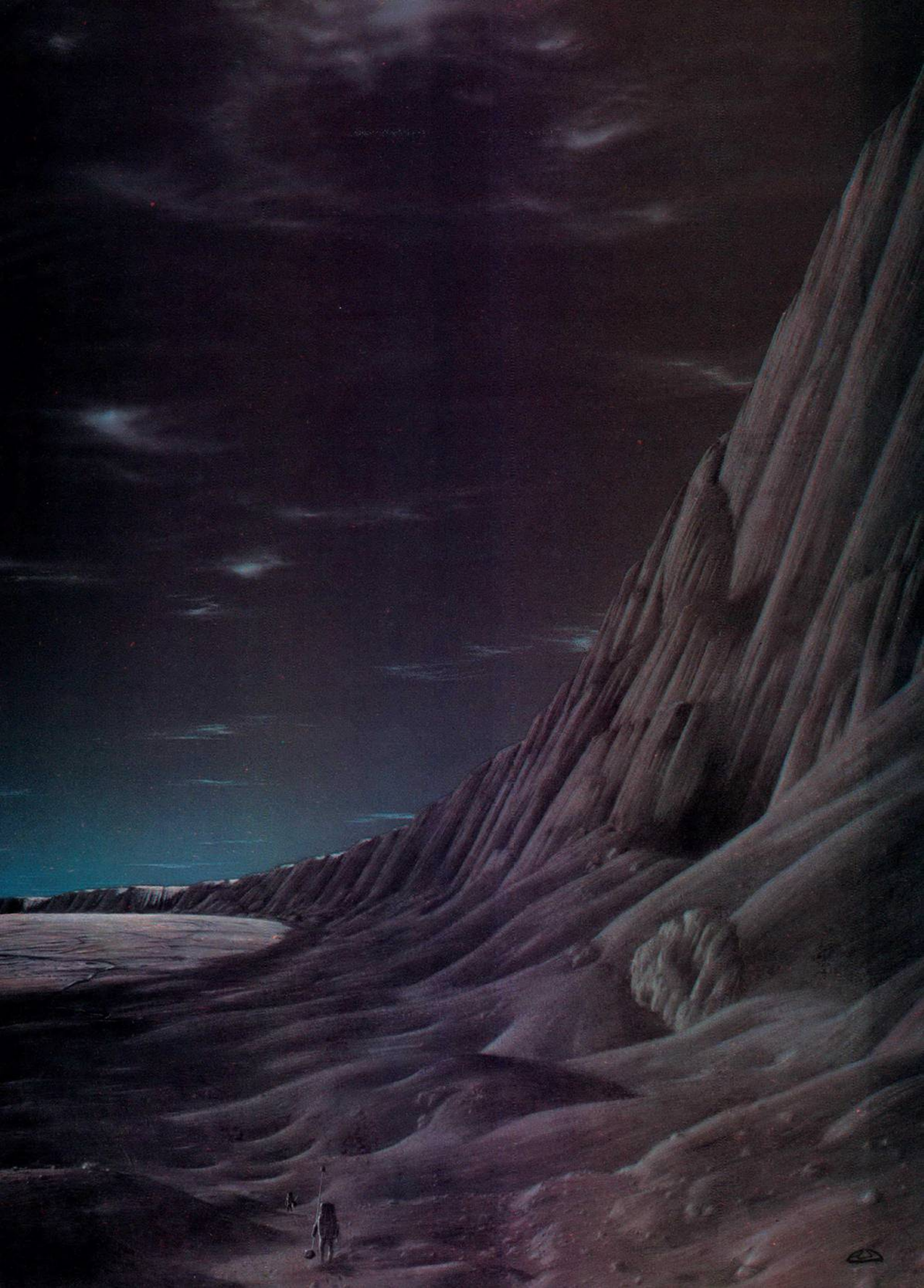
The appearance of these tails — especially their tendency to shed off tangentially from crater walls — suggests that they are wind related. It appears as if a thin layer of bright material is being removed — revealing a dark, wind resistant underlying surface. Indeed, following the end of the 1971 global dust storm, Syrtis Major was probably covered with a thin veneer of bright dust. In this hypothesis, subsequent westerly winds (blowing left to right in the picture) scoured off this dust veneer especially in the wakes of craters where the wind velocity is increased by the crater walls. This boosts the wind's ability to carry and remove dust.

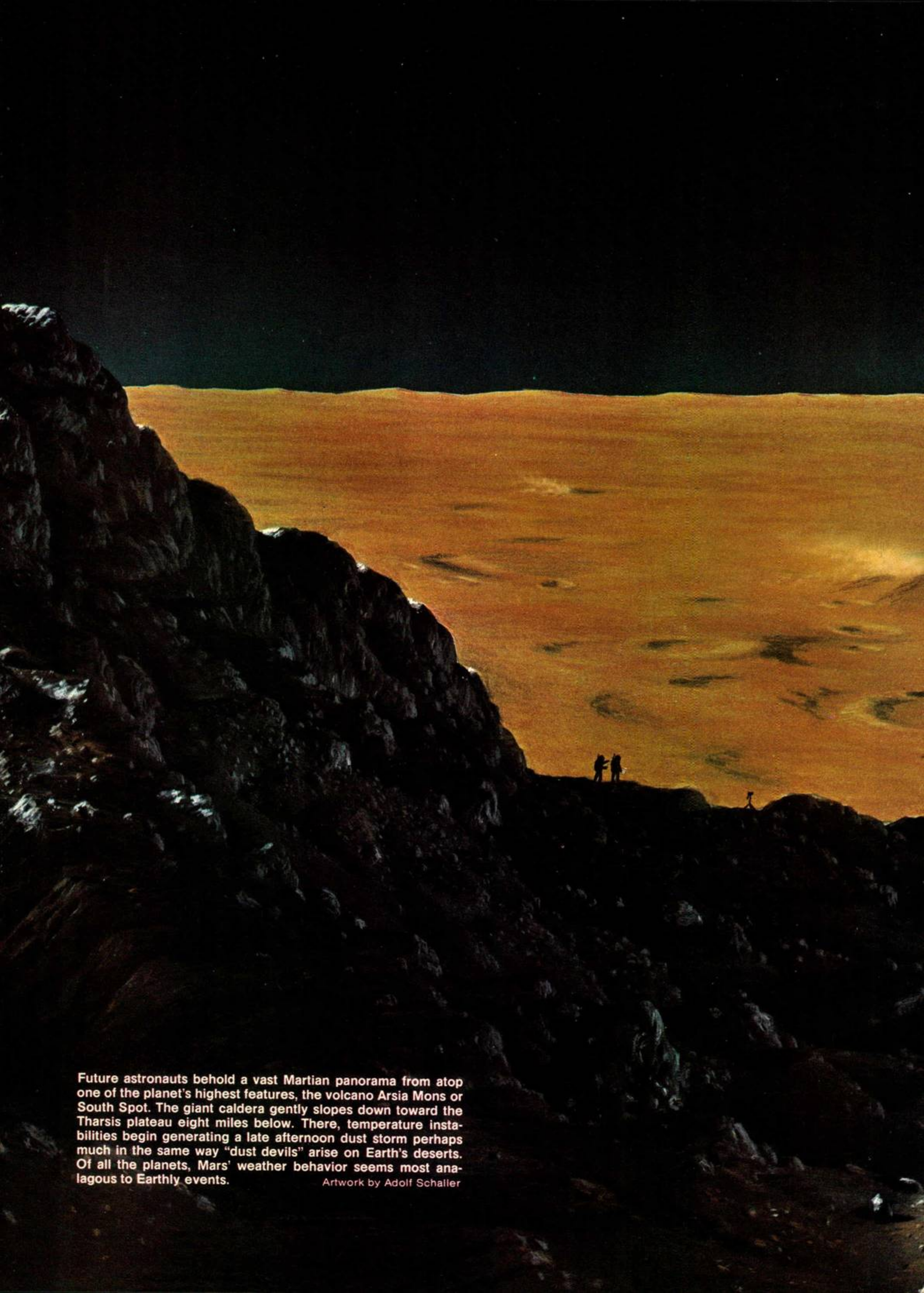
There are several possible explanations for why Mars has a two-tone surface of light and dark material. The most likely is that the surface layer consists of minerals of two general types. The darker material might be mostly unweathered, unoxidized, rich in heavy elements like iron, and poor in silica. The light material might consist of the weathering products of the dark material — minerals richer in silica and lighter in tone. The weathered material would also tend to have a finer texture since weathering tends to break up mineral grains. This effect would tend to increase its contrast relative to the dark material. Particle size plays a role in how bright a material will appear. If a rock is ground down, it will seem to get brighter since there are more particle surfaces to scatter light per unit of volume.

On Mars, the underlying bedrock is likely to be darker than the blanket of weathered material which in many places forms the visible surface. This blanket seems to be veneer-thin in some places, but thousands

Steep walls soar in a vast arc around the floor of the largest known volcano in the solar system, Olympus Mons (formerly called Nix Olympica). An exploration party carefully descends into the 40 mile wide mouth of the sleeping giant to collect rock samples and search for other clues telling when Olympus Mons last belched ash and molten lava. Overhead, ice crystal clouds make their frequent appearance as the 15 mile high mountain forces air to rise to higher altitudes where its water vapor cools and condenses into ice crystals.

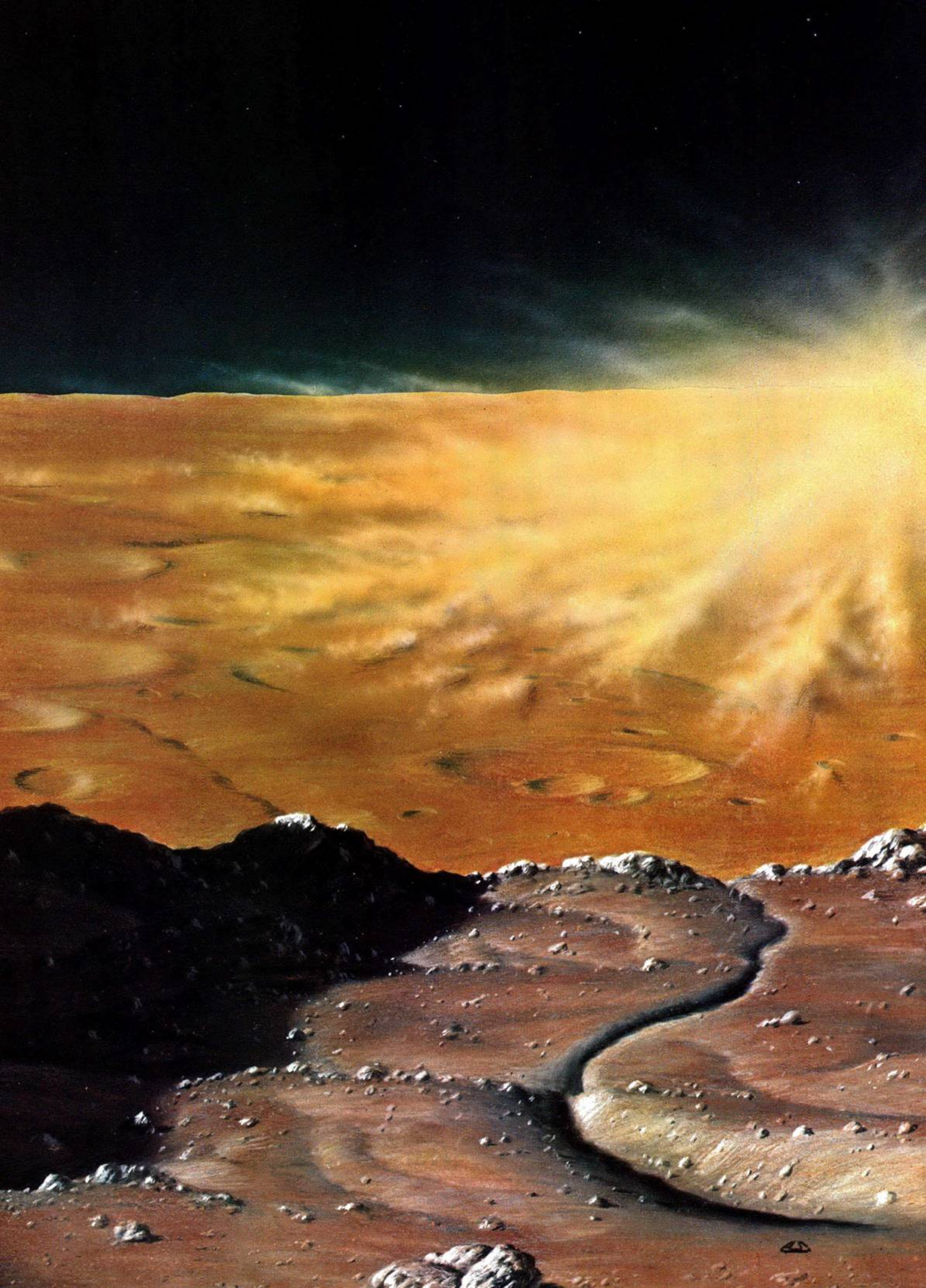
Artwork by Adolf Schaller





Future astronauts behold a vast Martian panorama from atop one of the planet's highest features, the volcano Arsia Mons or South Spot. The giant caldera gently slopes down toward the Tharsis plateau eight miles below. There, temperature instabilities begin generating a late afternoon dust storm perhaps much in the same way "dust devils" arise on Earth's deserts. Of all the planets, Mars' weather behavior seems most analagous to Earthly events.

Artwork by Adolf Schaller



of feet thick in other areas (for example, the laminated terrain in the polar regions).

The rapid development of dark streaks is best explained in terms of the stripping away by winds of a thin veneer of bright dust representing dust storm fallout. If this stripping away exposes a darker wind resistant stratum, we see the appearance of a dark streak. Dark streaks are, therefore, quite superficial; blowing away only a fraction of an inch of dust storm fallout might lead to the appearance of a conspicuous dark streak.

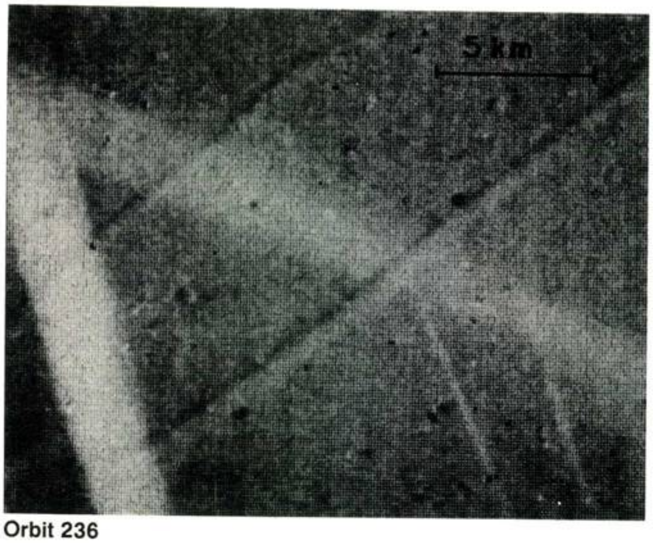
Bright streaks are definitely more permanent, and therefore probably more substantial. They may, in fact, correspond to large accumulations of bright sand and dust in the lee of some craters — much like the large lee dunes which trail behind hills in the Peruvian desert. Some of the Peruvian lee dunes are several hundred feet high and several miles long. If bright streaks are in fact such lee dunes, then short-term changes in their outlines are unlikely. They would be substantial accumulations of sand and dust which may take years to build up or to destroy. If this interpretation of bright streaks is correct, then Viking should find them essentially unchanged from the days of Mariner 9.

The darkening of Syrtis Major following the great storm was accompanied by similar darkening of many other areas. In some (Depressio Hellespontica, for example), this was due to the development and coalescence of randomly placed splotches. In others, like Syrtis Major, it was due to the development of dark streaks accompanying craters.

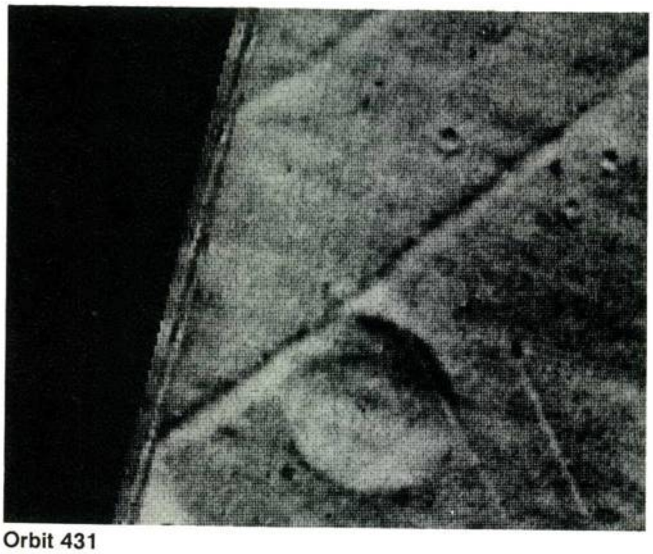
An unusual case is shown in picture 5 . On Orbit 108, there were a few dark crater tails in this bright section of Pandorae Fretum. Forty days later (Orbit 188), most of the area between craters was dark and crater tails were no longer evident. This again suggests that by the end of the dust storm, the region was coated with a veneer of bright dust. By Orbit 108, dust had been swept away only in the wakes of a few craters. But by Orbit 188, most of the area had been blown clean, leaving crater tails inconspicuous.

An episode of strong winds — winds strong enough to transport dust without being intensified by flow around crater walls — is evident during the 40 day intervals separating these two views. Significantly, the double rill running across the bottom half of the picture is still bright on Orbit 188. Being a depression, it must act as a dust trap — bright dust can be blown into it but not back out.

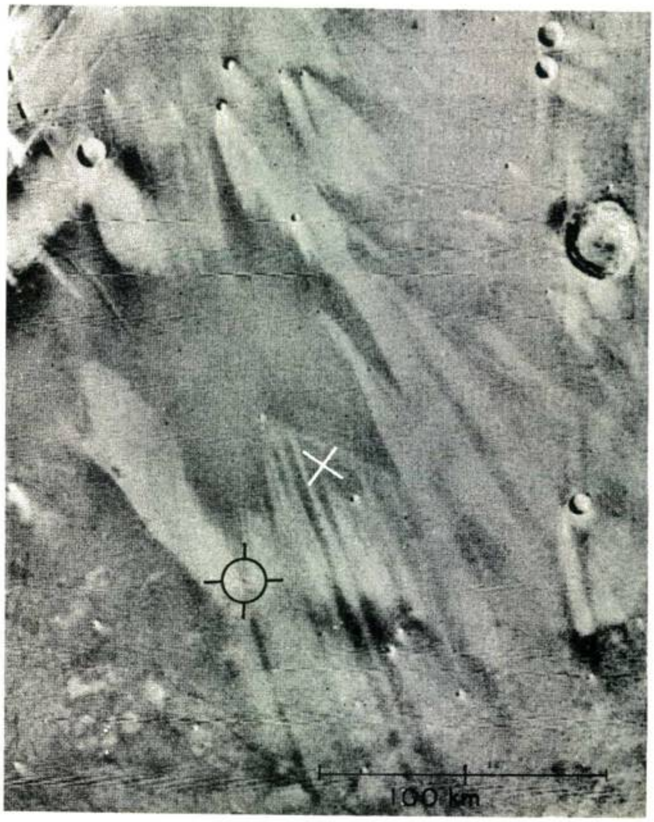
Following the end of the global dust storm in early 1972 were a number of local dust storms lasting several days. An example from Chryse (picture 6)



Orbit 236

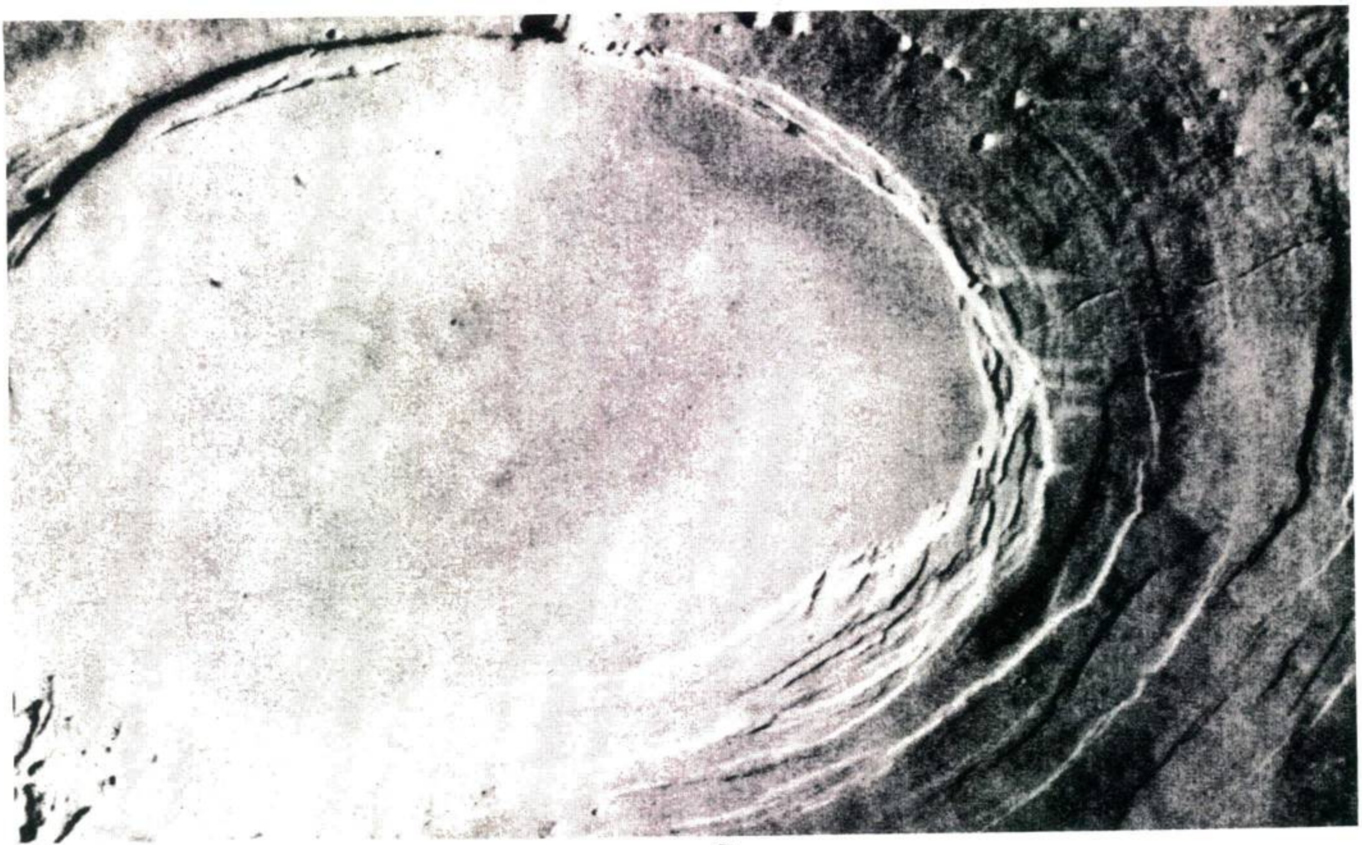


Orbit 431



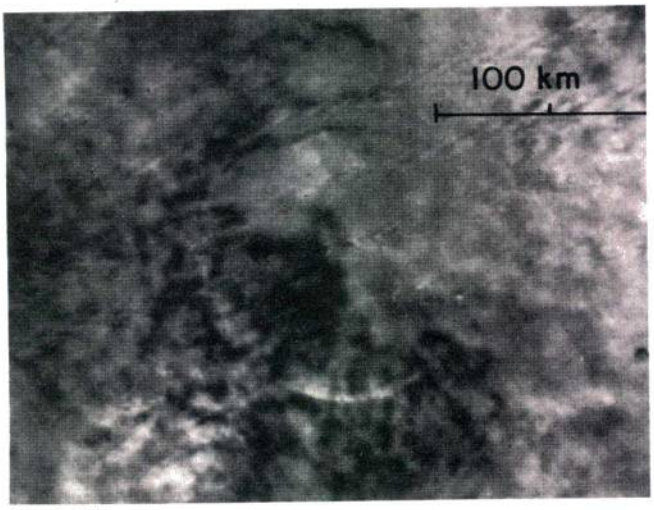
①

In the two frames above, a mysterious "new" crater appears in Tharsis (10 degrees south latitude, 107 degrees west longitude) between Orbits 236 and 431. Note how the nearby rill remains intact despite this seemingly new visitor. That is a giveaway that the crater was really an afterimage in Mariner 9's television system. In a wide-angle view of Tharsis (bottom), a circle points out the spurious crater's real location. The area that it appeared in is marked by the X.

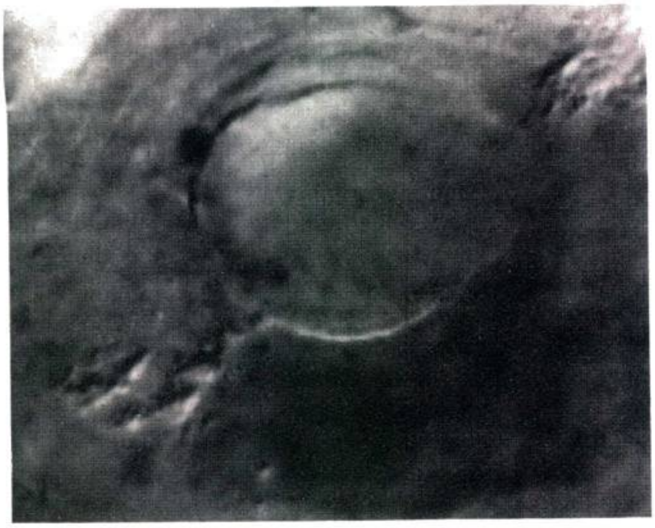


②

South Spot (4 degrees south latitude, 120 degrees west longitude), the largest volcanic crater on Mars, measures 75 miles across. In the bottom left frame, South Spot appears almost cloud-free on Orbit 178. Nineteen days later (Orbit 217), the caldera almost disappears under a blanket of cumuluslike clouds. Ice crystal clouds often form near Martian volcanos probably because they are relatively high objects.



Orbit 217

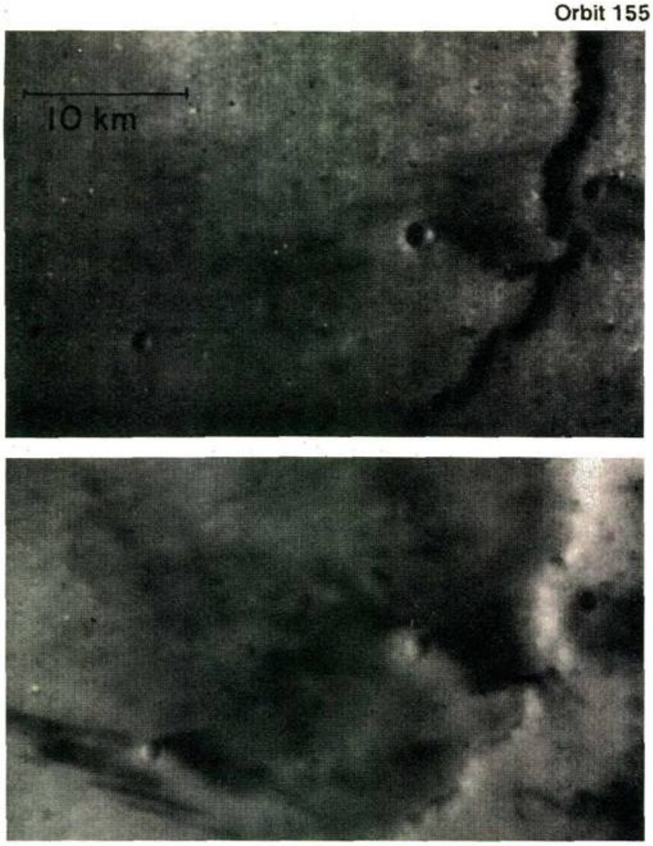


Orbit 178

shows that surface detail is obscured on Orbit 168, especially in the right half of the frame. Bright streaks trending west-east (left-right) are conspicuous; their western ends are sharply defined but become more diffuse toward the east (right). This pattern suggests that westerly winds are churning dust. Craters and other surface features appear 20 days later (Orbit 209) when the dust clears. Such local storms probably correspond to the yellow clouds frequently reported by Earth based observers.

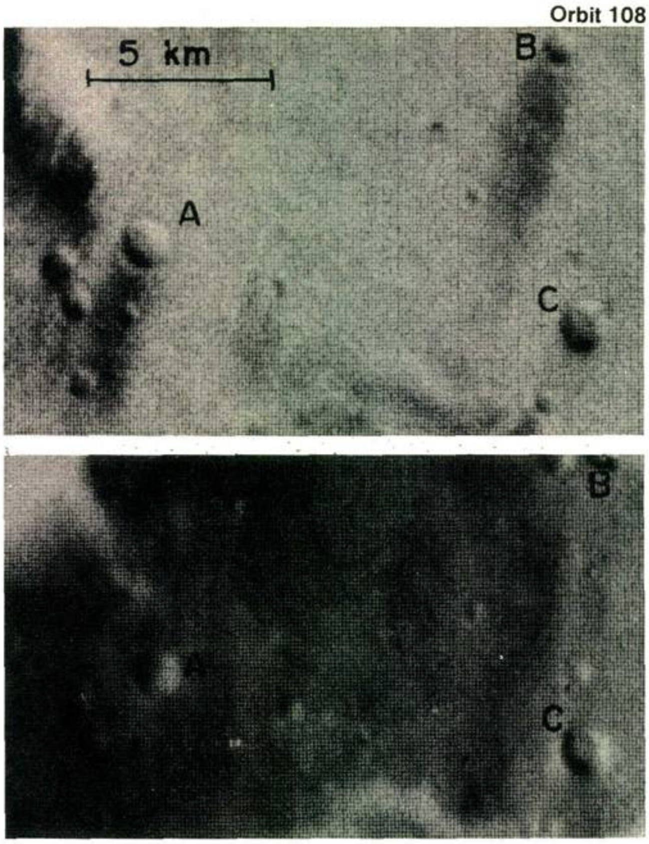
The terrain in Chryse is chaotic and apparently highly eroded making it a rich source area for wind-transportable dust. Chryse, incidentally, is the prime landing site for one of the two Viking spacecraft that will reach Mars in July 1976.

Besides wind streaking, clouds are another swiftly changing Martian event. In particular, condensation clouds were frequently observed by Mariner 9 in association with volcanic calderas such as the South Spot shown in picture 2. Earth based observers have often reported the formation of early afternoon clouds in this area. These clouds were frequently seen in Mariner 9 photographs of the South Spot both as very bright patches (the clouds themselves) or as dark blobs (cloud shadows). Since the elevation of the sun above the horizon at the time



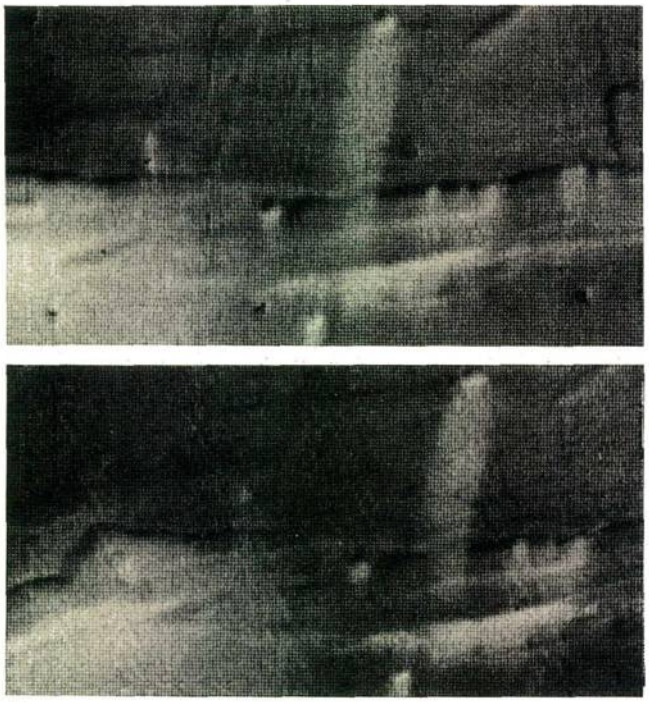
③

Dark streaks emanating from Martian craters noticeably develop during the 178 days separating these two Mariner 9 photos taken on Orbits 155 and 430. Their left to right orientation indicates strong westerly winds in this region of Syrtis Major (15 degrees north latitude, 282 degrees west longitude). The face of the scarp running down the right side of the frame is in shadow on Orbit 155, but illuminated on Orbit 430.



⑤

A dramatic example of post-dust storm darkening in Pandorae Fretum (30 degrees south latitude, 335 degrees west longitude): In the 40 days between Orbits 108 and 188, a layer of light surface dust is swept clean causing the dark streaks (Orbit 108) to vanish as the entire area takes on the same reflectivity, or albedo, as the streaks. Note that a double rill in the bottom half of the frame keeps its trapping of bright dust. Letters highlight craters visible in both frames.



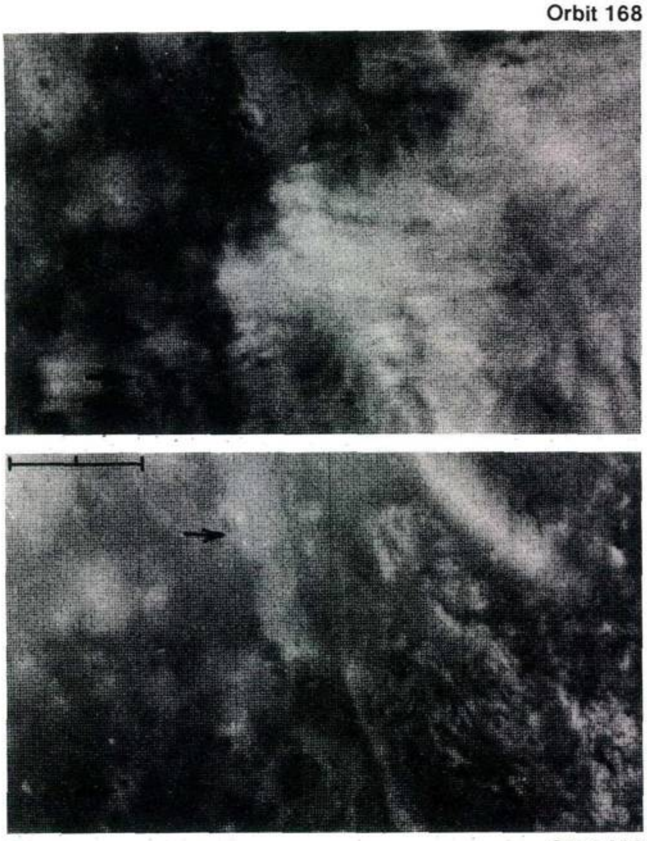
④

In the 19 day interval between these two views of a group of bright streaks in Tharsis (10 degrees south latitude, 107 degrees west longitude), no changes are evident. During the Mariner 9 mission no conspicuous changes in any bright streaks were detected anywhere on Mars.

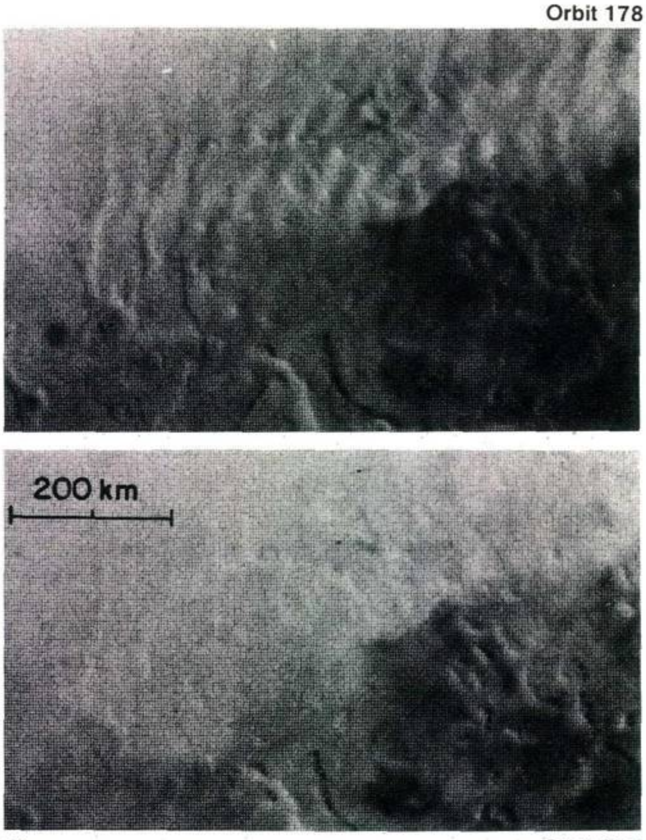
of each picture is known, the height of the clouds can be estimated from cloud shadows. Estimates place the clouds at less than five miles above the floor of the caldera. They are probably water condensation clouds since at these altitudes, the temperature is still too high for gaseous carbon dioxide (main constituent of Mars' atmosphere) to solidify into cloud particles.

Why are white clouds so often associated with volcanic calderas? Does it indicate local outgassing of water vapor? Although this possibility cannot be excluded, it seems more likely that the association between white clouds and volcanos results only because the volcanos are high. If a warm, relatively moist parcel of Martian "air" is forced to flow over such a high feature, the parcel will expand and cool — becoming supersaturated, and leading to the formation of clouds.

Changes were frequently observed in the edge of the northern polar hood which covers the northern latitudes of Mars (beyond 50 degrees north latitude) during the northern hemisphere's winter and early spring. During winter the hood probably consists of carbon dioxide condensation clouds at low altitudes. The cloud patterns at the hood's edge (picture 7) seem to change continuously. Sometimes the edge of



⑥
The local dust storm in Chryse (14 degrees north latitude, 33 degrees west longitude) shows as a bright cloud obscuring *surface detail in the right half of the frame on Orbit 168.* The sharp western edge (right side of frame) probably defines the region where westerly winds are lifting bright dust into the atmosphere. Twenty days later on Orbit 209, the bright cloud has dissipated. Arrows point to some prominent craters visible in both views.



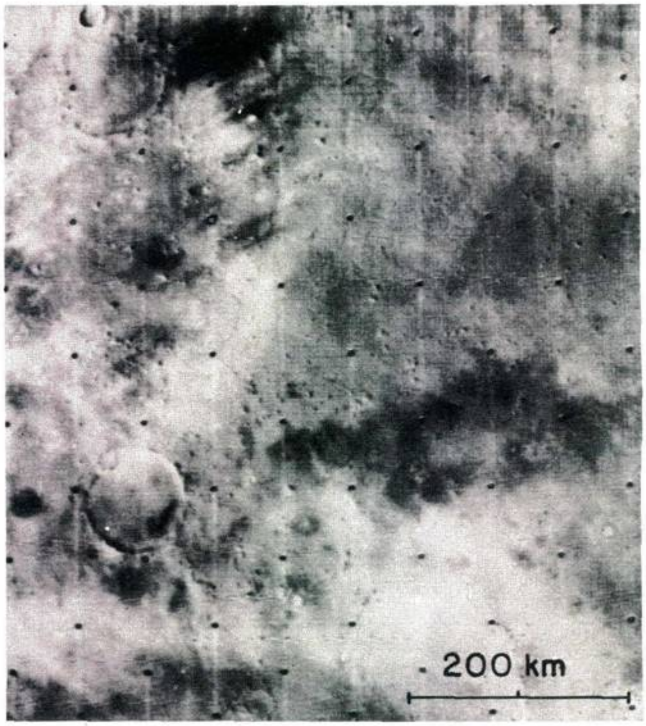
⑦
The edge of the north polar hood — clouds blanketing the northern polar cap during winter — appears near Ismenius Lacus (43 degrees north latitude, 340 degrees west longitude). On Orbit 178, a thin veil of herringbone clouds is prominent in the upper half of the frame. By Orbit 217, 19 days later, the cloud sheet appears featureless.

the hood shows a wave structure indicating westerly winds, while at other times it is structureless and diffuse.

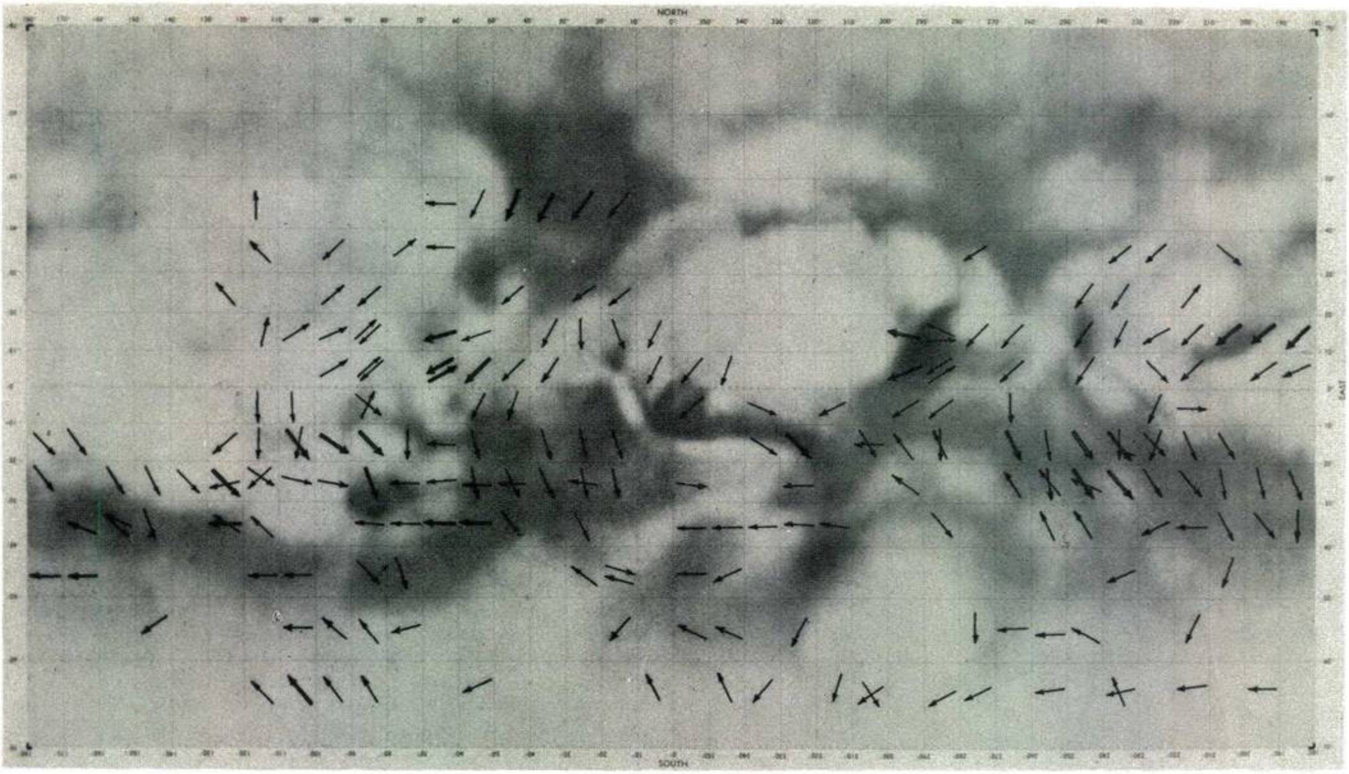
In the course of comparing Mariner 9 pictures, many enigmatic changes were uncovered. Some are no doubt real; others are spurious. The change in picture 8 is real. The dark streaks seen in this frame are absent on later orbits indicating that they are probably cloud shadows. Although the clouds are invisible, these shadows run diagonally across the picture in a direction consistent with the direction of sunlight, as judged by the shadows of crater walls. The slight waviness in the picture from Orbit 202 can be attributed to clouds which are too thin to obscure surface detail.

Picture 1 shows an example of a spectacular — but unfortunately spurious — change. The picture comparison implies that a new crater was formed sometime between Orbits 236 and 431, but this cannot be what happened for many reasons. Most importantly, the crater does not have a fresh appearance and it is cut by a rill which was present on Orbit 236 — indicating that the rill is *older* than the crater.

Intensive detective work by T. Thorpe of the Jet Propulsion Laboratory has solved the mystery — the crater outline is a leftover image! Traces of a pre-



⑧
In this late northern winter view of Propontis (40 degrees north latitude, 185 degrees west longitude), only the ghostly shadows of extremely thin — almost transparent — clouds are noticeable. The southern limit of the north polar hood lies close to the upper edge of the frame.



Bright and dark crater-associated streaks paint natural wind direction markers across Mars' surface. This map's arrows indicate the direction the streaks point and hence the direction of Martian winds. Thick arrows suggest some prevailing wind directions. Double arrows identify areas of abundant wind streaks.

viously recorded scene remained on the vidicon screen of Mariner 9's camera for two or three subsequent exposures. In general, the intensity levels of these "after images" were insignificant – but occassionally the residual image was strong enough to show up clearly on following exposures.

This is precisely what happened on the Orbit 431 picture . The previous camera exposure photographed a crater nearby. Although this image was not transmitted to Earth, the camera's pointing direction at that time can be reconstructed from the tracking data. Traces of this image remained on the vidicon when the next exposure was made – and thus a spurious crater appeared. Unfortunately, there are no recorded Mariner 9 close-up pictures of this crater alone – but it can be seen in a wide-angle resolution of the picture. The area that the crater deceptively appeared in lies at the point marked by the "X".

The existence of such a residual image suggests that a small number of other Martian craters may also have a dubious origin. Variable feature picture comparisons have so far been carried out for only a small fraction (about one percent) of the Martian surface. There could be perhaps several dozen other spurious images of craters which look perfectly convincing on a single Mariner 9 picture. But only a few of these might be large enough to warrant making changes on Mariner 9 Mars' maps. To be sure, all mapped craters on Mars should be observed on at least two independent photos.

Mariner 9's more than 7,000 pictures recorded surface changes occurring over only a relatively short period of time – less than half the Martian year. However, close-up monitoring of Mars will resume in 1976, when two Viking spacecraft are scheduled to orbit the red planet. As the landers on board each vehicle descend to the Martian surface to search for life, the remaining orbiter section will use high resolution television to look for future landing sites. The pair of orbiters will observe late spring and summer changes in the Martian northern hemisphere, complimenting the winter season Martian portrait taken by Mariner 9.

Combining photography from both the Mariner and Viking missions should provide a more nearly complete picture of the red planet's annual weather pattern. Such an overall view could help generalize the science of meteorology by including the weather of more than one world, with the promise of new insights into the complex behavior of our own atmosphere.

Dr. Lynn Quam of Stanford's Artificial Intelligence Laboratory has pioneered many of the computer picture processing techniques used to analyze spacecraft television data. The picture differencing routines used to study changes on Mars were developed by Quam in conjunction with Botand Eross and Robert Tucker, also of Stanford. Recently Quam has been working on the development of intelligent robots for the unmanned exploration of planets. Dr. Carl Sagan and Dr. Joseph Veverka of Cornell University's Laboratory for Planetary Studies interpreted the pictures processed by their colleagues. Both Sagan and Veverka are frequent contributors to ASTRONOMY.

GAZER'S GAZETTE

The Realm of the Galaxies

by

Thomas C. Bretl

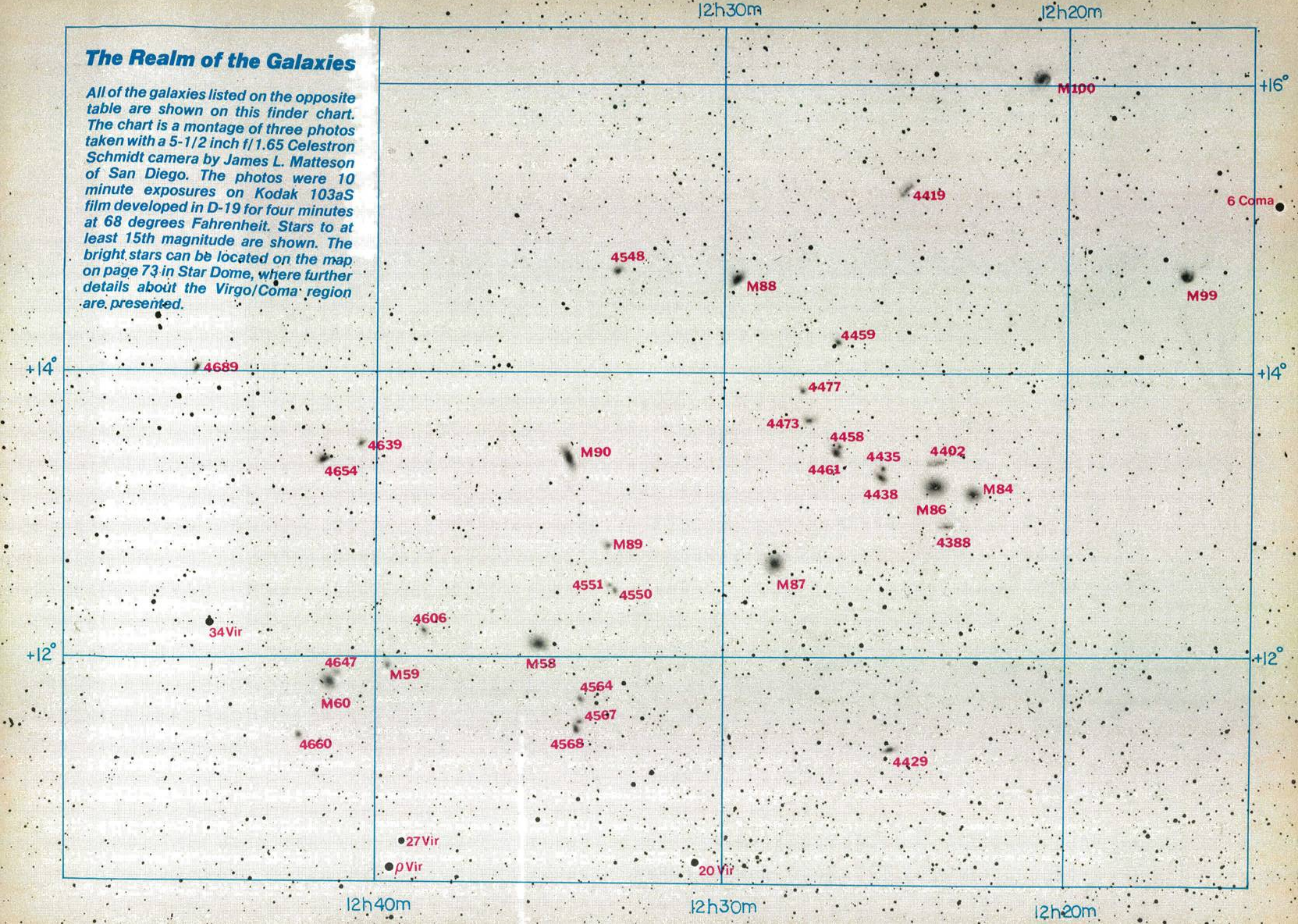
When the first crude spyglasses were turned toward the night sky during the 17th century, they revealed small hazy patches of light that were largely ignored by scientists of that time. Later, observers using larger telescopes found more and more of these nebulous objects — some of which turned out to be clusters of individual stars, while others were identified as clouds of dust and gas. But even as recently as 60 years ago, many of them were still mysterious.

During the last half of the 18th century, Sir William Herschel observed more than 1,000 of these unresolvable nebulae. His powerful 18 and 48 inch telescopes were able to unveil few, if any, of their secrets. Herschel, however, had a theory: Perhaps each of these small hazy spots was an entirely separate galaxy, far beyond the boundaries of our own Milky Way. It was an exciting idea, but at the time there was no way to check it out. Herschel's guess — which was shared by some of his contemporaries — was correct, but it was not to be confirmed until many years after his death.

Today, astronomy enthusiasts equipped with

The Realm of the Galaxies

All of the galaxies listed on the opposite table are shown on this finder chart. The chart is a montage of three photos taken with a 5-1/2 inch f/1.65 Celestron Schmidt camera by James L. Matteson of San Diego. The photos were 10 minute exposures on Kodak 103aS film developed in D-19 for four minutes at 68 degrees Fahrenheit. Stars to at least 15th magnitude are shown. The bright stars can be located on the map on page 73 in Star Dome, where further details about the Virgo/Coma region are presented.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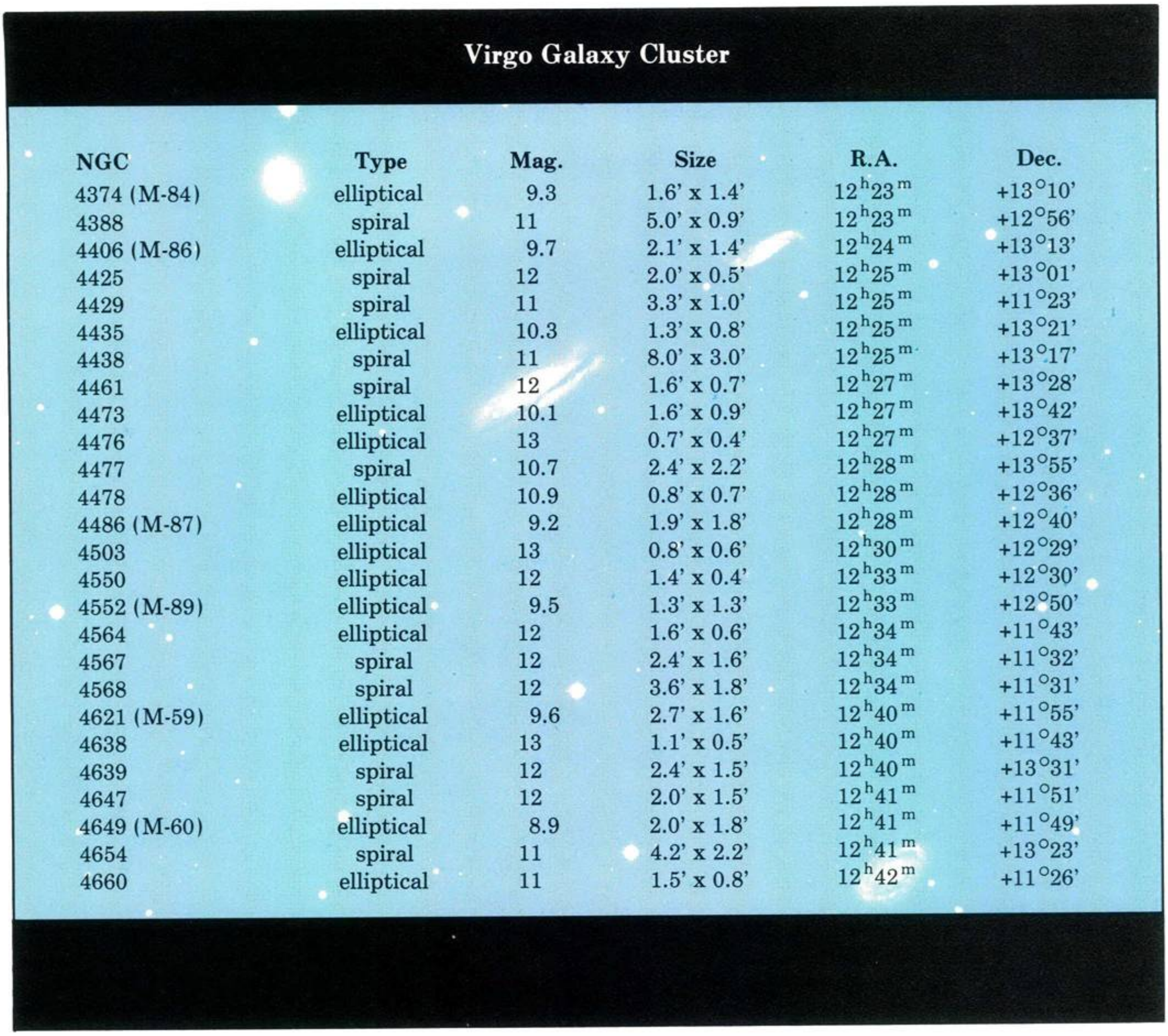


Virgo Galaxy Cluster

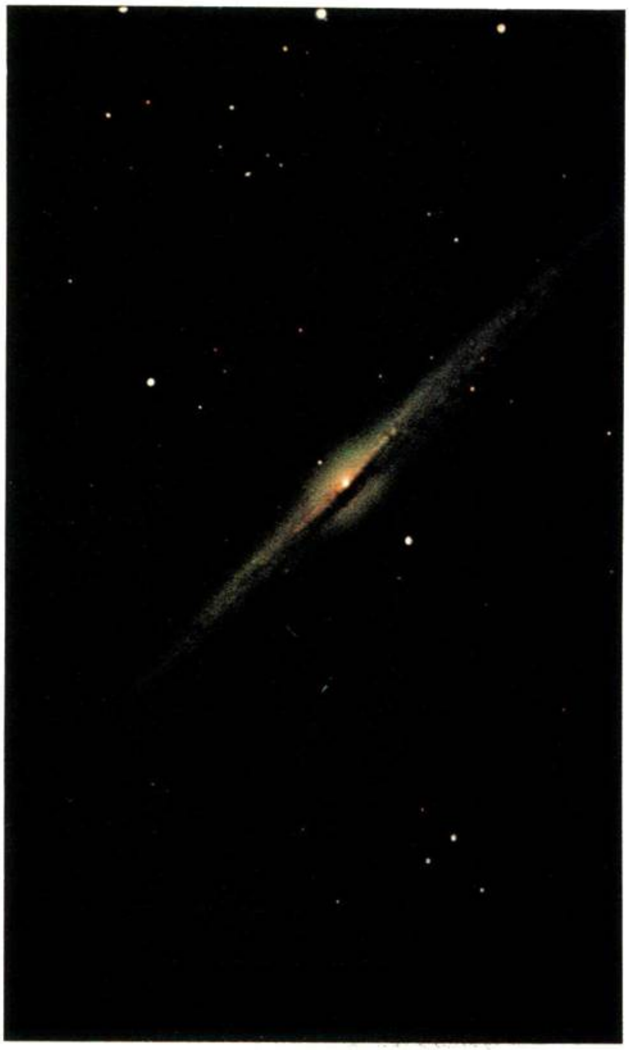
NGC	Type	Mag.	Size	R.A.	Dec.
4374 (M-84)	elliptical	9.3	1.6' x 1.4'	12^h23^m	+13°10'
4388	spiral	11	5.0' x 0.9'	12^h23^m	+12°56'
4406 (M-86)	elliptical	9.7	2.1' x 1.4'	12^h24^m	+13°13'
4425	spiral	12	2.0' x 0.5'	12^h25^m	+13°01'
4429	spiral	11	3.3' x 1.0'	12^h25^m	+11°23'
4435	elliptical	10.3	1.3' x 0.8'	12^h25^m	+13°21'
4438	spiral	11	8.0' x 3.0'	12^h25^m	+13°17'
4461	spiral	12	1.6' x 0.7'	12^h27^m	+13°28'
4473	elliptical	10.1	1.6' x 0.9'	12^h27^m	+13°42'
4476	elliptical	13	0.7' x 0.4'	12^h27^m	+12°37'
4477	spiral	10.7	2.4' x 2.2'	12^h28^m	+13°55'
4478	elliptical	10.9	0.8' x 0.7'	12^h28^m	+12°36'
4486 (M-87)	elliptical	9.2	1.9' x 1.8'	12^h28^m	+12°40'
4503	elliptical	13	0.8' x 0.6'	12^h30^m	+12°29'
4550	elliptical	12	1.4' x 0.4'	12^h33^m	+12°30'
4552 (M-89)	elliptical	9.5	1.3' x 1.3'	12^h33^m	+12°50'
4564	elliptical	12	1.6' x 0.6'	12^h34^m	+11°43'
4567	spiral	12	2.4' x 1.6'	12^h34^m	+11°32'
4568	spiral	12	3.6' x 1.8'	12^h34^m	+11°31'
4621 (M-59)	elliptical	9.6	2.7' x 1.6'	12^h40^m	+11°55'
4638	elliptical	13	1.1' x 0.5'	12^h40^m	+11°43'
4639	spiral	12	2.4' x 1.5'	12^h40^m	+13°31'
4647	spiral	12	2.0' x 1.5'	12^h41^m	+11°51'
4649 (M-60)	elliptical	8.9	2.0' x 1.8'	12^h41^m	+11°49'
4654	spiral	11	4.2' x 2.2'	12^h41^m	+13°23'
4660	elliptical	11	1.5' x 0.8'	12^h42^m	+11°26'

smaller, but more efficient, telescopes can repeat the observations of Herschel and rediscover a surprising number of his "extragalactic nebulae". One of the most inviting regions of the sky lies along the Virgo-Coma Berenices border, 10 degrees east of Denebola [Beta (β) Leonis]. Here our vision is not cut off by the dust clouds of the Milky Way, and the light from an extraordinary number of galaxies is free to shine through to our eyes from millions of light-years beyond. In an area of approximately 10 square degrees, more than a dozen Messier objects can be found — and in one amazingly congested region of less than 1/10 that size, no fewer than 35 of Herschel's galaxies can be seen with a 12 inch reflector. Let's try to find our way through this confusing maze of objects.

On the basis of their total magnitudes, one might reasonably expect that many of the galaxies in the Virgo-Coma region should be easily visible in a two or three inch refractor. Unfortunately this is not the case.

Galaxies are extended objects — their brightness is spread out — and they are not nearly as conspicuous as single stars of the same magnitude. To see how great a difference this can make, watch what happens to the apparent brightness of a star as you slowly put it out of focus. The blurred stellar image grows progressively dimmer as it grows larger, and before long it disappears entirely. Similarly, the larger the galaxy you observe, the more difficult it is to see. Its light is so spread out that it contrasts very poorly with the surrounding sky. Most galaxies have this low "surface" brightness, and they are difficult objects in all but the largest telescopes.

For much the same reason, sky conditions are also of critical importance to the galaxy hunter. If the sky is hazy, or if there is excessive interference from the moon, the contrast between a galaxy and its background will be further diminished. A higher power partially overcomes this problem for double or variable star observers since the higher magnification reduces the brightness of the sky without



U.S. Naval Observatory Photograph

This giant galaxy known as NGC-4565 is seen nearly edge-on, its bulging nucleus of stars partly obscured by dust laden spiral arms. Although a great distance from the main concentration of the Virgo galaxy cluster, this star city is believed to be part of that group. Observing tips and the galaxy's location are detailed in Star Dome.

noticeably affecting the brilliance of the stars. When observing galaxies, however, increased magnification also enlarges the object's size, spreading out its brightness even more, and making it harder — not easier — to see.

Galaxies are very elusive objects, and many observers — excited at the prospect of seeing several of them within every field of view — have been sorely disappointed when they were able to find few or none at all. To help you spend a successful and rewarding night, we offer the following suggestions:

1) If possible, use a telescope with an aperture of at least six inches. Small refractors will reveal some of the brighter galaxies, but considerable light gathering power is necessary to fully appreciate the magnificence of the Virgo-Coma region.

2) Pick the best possible time and place to observe. Try to find an observing site where the skies are dark, far from disturbing city lights. Choose a moonless night when the sky transparency is exceptional and sixth magnitude stars are visible to the naked eye.

3) Wait until the Virgo-Coma region is high in the sky — to avoid looking through the thicker atmosphere near the horizon — and then observe using your lowest power eyepiece. Excessive magnification is no help in observing galaxies, and a very low power (five to eight per inch of aperture) is almost always best.

4) Always allow your eyes enough time to become well adapted to the dark, and use a red light to consult maps and charts. If you have just left a brightly lit room, your eyes will be completely insensitive to the subtle glow of a distant galaxy.

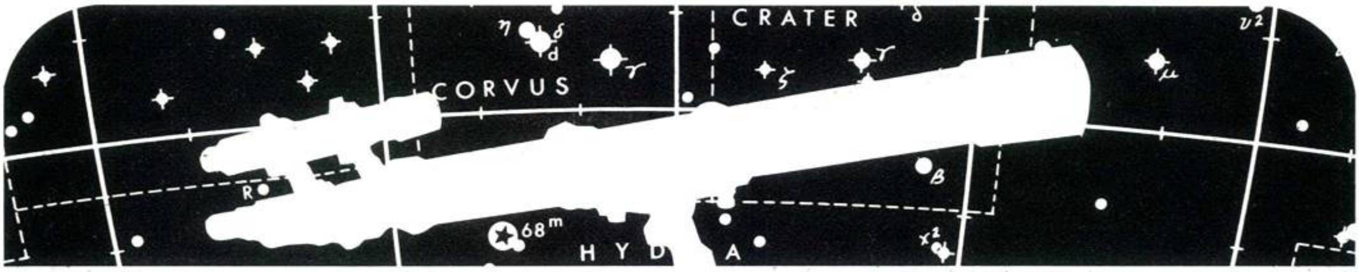
Suppose the night is dark, the sky is clear, and you are ready to begin your search. Where do you start? One good place is at 6 Coma, a fifth magnitude star five degrees east of Denebola. Two 10th magnitude galaxies (M-98 and M-99) should be visible within the same field of view, and from there you can slowly work your way southeastward toward Rho (ρ) Virginis. On the way, you will pass through the most galaxy-populated region of the sky!

Once you have found 6 Coma, it will be easier to hop from galaxy to galaxy than to locate other guide stars. (There are so many galaxies here that each one shows the way to the next.) Use the accompanying map to help you, and consult the table for sizes and magnitudes of individual objects. Keep in mind that you cannot expect to see galaxies which are as faint as the limiting stellar magnitude of your telescope. As a general rule, only galaxies at least one magnitude brighter than that limit can be seen. And try the averted vision technique (looking out of the corner of your eye) to spot the faintest ones.

Two degrees southeast of 6 Coma is the extremely congested region that was mentioned above. Here you can see as many as nine galaxies all in the same field of view. Two Messier objects (M-84 and M-86) are easy because of their small size, brightness and prominent nuclei, but the same cannot be said for several of the galaxies which surround them. NGC-4402 and NGC-4413 are extremely faint and inconspicuous, while NGC-4388 — because of its large size — is also a difficult object. Even if your telescope is of sufficient aperture, don't expect to see them immediately. Sweep slowly back and forth through this area, and use the corner of your eye. Or cover your eyes completely for a few minutes and let them get totally adapted to the dark. What was invisible before may suddenly become quite prominent.

As you continue to explore this extraordinary region, you will surely be impressed by the wide variety of galactic shapes, sizes and magnitudes. There are large, bright, oval galaxies such as M-90; compact bright ones like M-87, and apparently colliding pairs such as NGC-4567 and 4568.

The examples are almost endless, and once you start looking you may find yourself returning to this place again and again.



Rich Field Telescopes

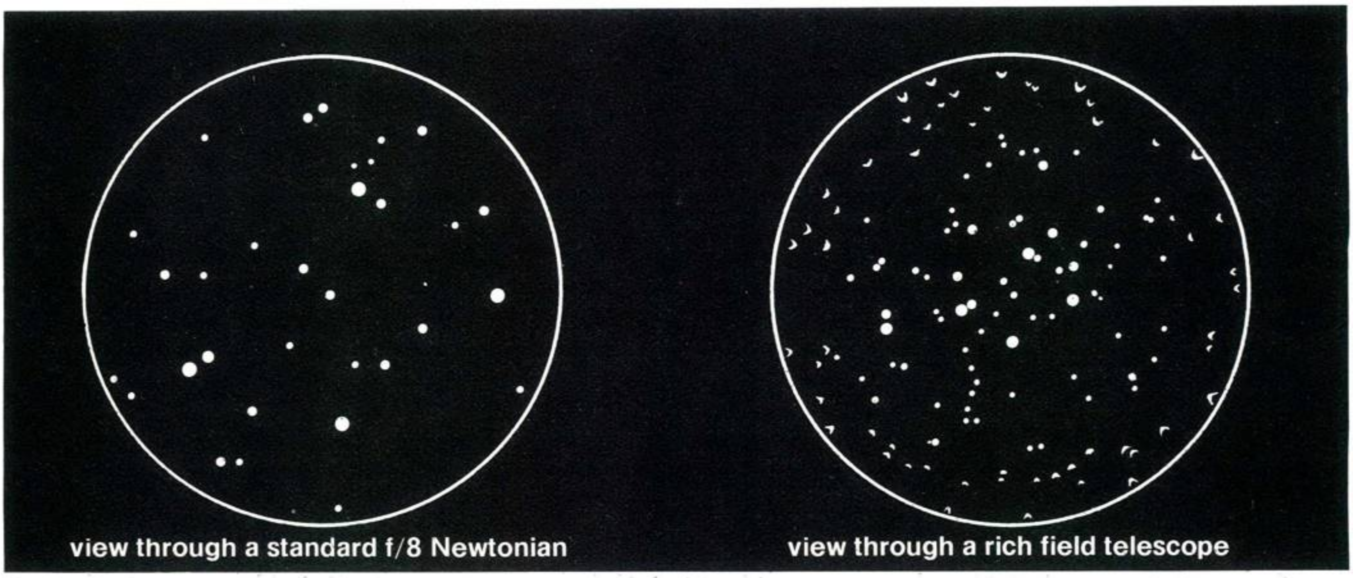
by

Thomas C. Bretl

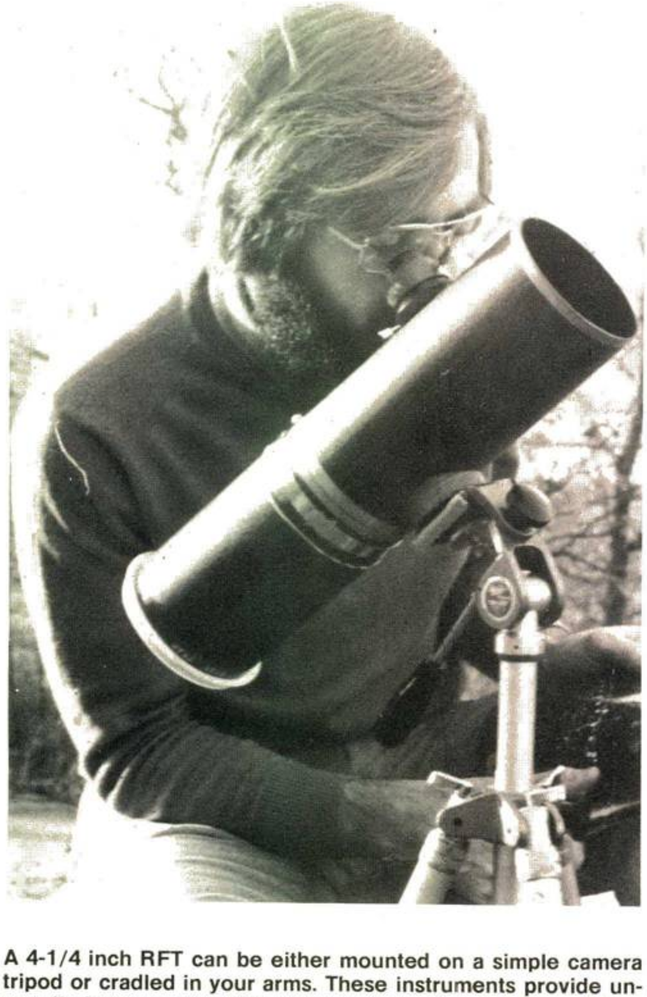
Although it is often tempting to try high power eyepieces, they usually give disappointing results. Few objects are revealed in greater detail when viewed under high magnification, and some can even be magnified "out of existence" when extreme high power is used. The size and quality of a telescope's objective lens (or primary mirror) sets a theoretical limit on its resolution, and no high power eyepiece is capable of overcoming that limit. Usually beyond a magnification of about 50 times the telescope's aperture (measured in inches), only hopelessly dim and fuzzy images are produced. The best images, in fact, are almost always obtained at magnifications far below this "highest useful" level.

A *rich field telescope* (RFT) carries this principle to an extreme by forsaking magnification in exchange for a bright image over a very wide field of view. The heart of the instrument is a mirror or objective lens of short focal length relative to its diameter (low f-ratio). This results in magnifications of only three to four times the aperture without the need of using highly corrected (and expensive) long focal length eyepieces. Because such a telescope combines high light gathering power with a very wide field, it reveals more stars in one view than any other type of telescope — hence the name rich field telescope. At the same time, the objective's short focal length means that the instrument is usually very light and compact; it can be mounted simply, or even cradled in the observer's arms.

Although they are not usually thought of as telescopes at all, certainly the most popular rich field telescopes are 7 x 50 binoculars. Combining a relatively large objective diameter (50mm) with


view through a standard f/8 Newtonian
view through a rich field telescope

These two views of the same part of the sky show the main advantage and disadvantage of a rich field telescope. The big plus is the RFT's inherent wide field of view — double the width of standard Newtonian reflectors. The penalty is an unavoidable flaring of images toward the edge of the field — a distortion called coma.



A 4-1/4 inch RFT can be either mounted on a simple camera tripod or cradled in your arms. These instruments provide unexcelled views of the Milky Way and bright star clusters. (Telescope shown is a Star-Trap.)

short focal length and very low (seven) power, binoculars produce the largest exit pupil the human eye can accommodate — about seven millimeters. Thus, they utilize the two inch lens diameter efficiently and form the brightest images possible for the aperture. Appropriately, 7 x 50 binoculars are called *night glasses*.

Many observers underestimate the many beautiful objects they can see with "just" binoculars. Stars as faint as 10th magnitude should be visible under good seeing conditions, and that means that most of the Messier objects are well within their range. In addition, however, dense star fields of the Milky Way — impossible to see in their entirety with conventional telescopes — fit nicely into the 7 x 50's five to eight degree field of view. Particularly in the summer, you can treat yourself to hours of "sweeping" across the especially star-rich skies. How many clusters and nebulae can you pick out in Sagittarius? Perhaps many more than you think. And can you find the North America nebula in Cygnus? It is a very difficult object in larger telescopes.

For more light gathering power and somewhat greater magnification, many observers choose an f/4 four or six inch reflector with an economical one inch Kellner eyepiece. This rich field combination yields 16 power on the four, 24 power on the six inch, and a field of view more than two degrees in diameter with either telescope. For viewing large galactic clusters and extended nebulae, an RFT of this size is a joy to use.

The RFT is especially recommended for searching out any elusive object — whether it be a comet or distant galaxy. Best of all, a six inch RFT has a tube only two feet long (weighing less than 10 pounds), which can be used as a hand held instrument. Little time is needed to set it up and a sturdy mount is not important. Just cradle the telescope in your arms and you're ready to begin a night's observing.

Although small and portable, a six inch RFT is a powerful instrument capable of showing a wealth of deep sky objects. In the spring and early summer, for example, it can be used to explore the cluster of galaxies in Virgo and Coma Berenices. Its light gathering power is sufficient to reveal a great many members of this group, and its wide field of view makes locating and identifying individual galaxies a much easier task. Later in the summer, the area near Mu Sagittarii provides an attractive richest field target. The beautiful Lagoon and Trifid nebulae (M-20 and M-8) are found just south of this star, while to the north lies an extraordinarily dense star field strewn with both rich clusters and mysterious "starless" regions. Good fields of view can be found here with any telescope, but the RFT shows so much at once that the vastness and complexity of our own galaxy is strikingly apparent.

Along with all the good things that can be said about the rich field telescope, some mention should be made of its bad points as well. The images near

6 inch RFT requires no mount

Standard 6 inch Newtonian

Cave Optical Co. Photographs

The portability of a rich field telescope is due to its small size and the simpler requirements for a mounting. Even a finderscope is not necessary because the wide field of view makes locating sky objects a breeze.

the edge of the RFT's wide field of view are far from perfect due to an aberration known as *coma*.

Coma is common to all Newtonian reflectors. It is neither particularly noticeable nor objectionable in an f/8 telescope, where the curve of the mirror is slight and the field of view is not large — but it can be quite annoying in an RFT. There is no simple way to eliminate coma from either short focus reflectors or refractors, so most rich field observers are forced to live with it. Without question, coma detracts from the overall quality of the view — but usually this seems a small price to pay for such a large and bright celestial vista. To the astrophotographer, however, coma can be intolerable; for him the only solution is to "stop down" the telescope (reduce its aperture) to a focal ratio of f/6 or greater.

The RFT has the reputation of being an inferior instrument for observing the planets. However, while high power views of the planets are often disappointing, its reputation is not entirely deserved. Certainly it is not the ideal telescope for observing planets, but it should provide very satisfactory images — *if* it is well made and properly aligned.

Short focal length mirrors must be very carefully figured if they are to focus light as precisely as mirrors of longer focal length. In addition, even a "perfect" mirror will produce coma plagued images in the center of the field if it is not carefully aligned with the rest of the telescope. You can correct alignment yourself, but the optics must be excellent to begin with.

Because rich field telescopes are designed for wide fields of view, the diagonal (or secondary mirror) is larger than in f/8 reflectors. This oversized diagonal generally decreases planet image quality. To combat this, some observers remove the large diagonal and replace it with a smaller one when observing planets.

Moderate and high powers can be attempted with rich field telescopes, but short focal length eyepieces are not recommended to this end. Instead, use a good Barlow lens to double or triple the magnifying ability of long focal length eyepieces. As mentioned, long focal length eyepieces are more highly corrected and provide the added bonus of long eye relief (which is mighty important if you wear glasses!).

While specifically designed for low power, ultrawide field views of the sky, given a good mirror that is properly aligned, you will find that a rich field telescope can be a versatile, multipurpose instrument.

In the final analysis, however, the letters RFT refer more to a certain "spirit of observing" than they do to a particular type of instrument. All telescopes offer a wide range of possible magnifications, and it is up to the observer to decide which one to use. For those who love to sweep the skies at a leisurely pace, and who rarely succumb to the temptation of high power, any telescope can quickly become an RFT. Just take out the lowest power eyepiece and wait for the next clear night. ◆

SKY ALMANAC

Venus Dominates as Summer Begins

The brilliant sentinel in the June evening sky is Venus, now at its greatest apparent distance from the sun and in prime observing position. The other bright planets — Mercury, Mars, Jupiter and Saturn — are all in poor or impossible observing locations, but this dull situation is spiced up by a rare close conjunction of Mars and Jupiter.

Summer begins — according to the official rules — at 8:27 p.m. EDT June 21 when the sun reaches its maximum apparent distance north of the equator. Long days and very late sunsets are the result.

Venus

The superbrilliant white "star" in the western sky these evenings is Venus. The dazzling planet is visible for a full three hours after sunset, slowly being carried down to the western horizon during that time by Earth's rotation. On the evening of the 13th, the crescent moon and Venus will be within 10 degrees of each other — a stunning sight worth both unaided eye and telescopic scrutiny.

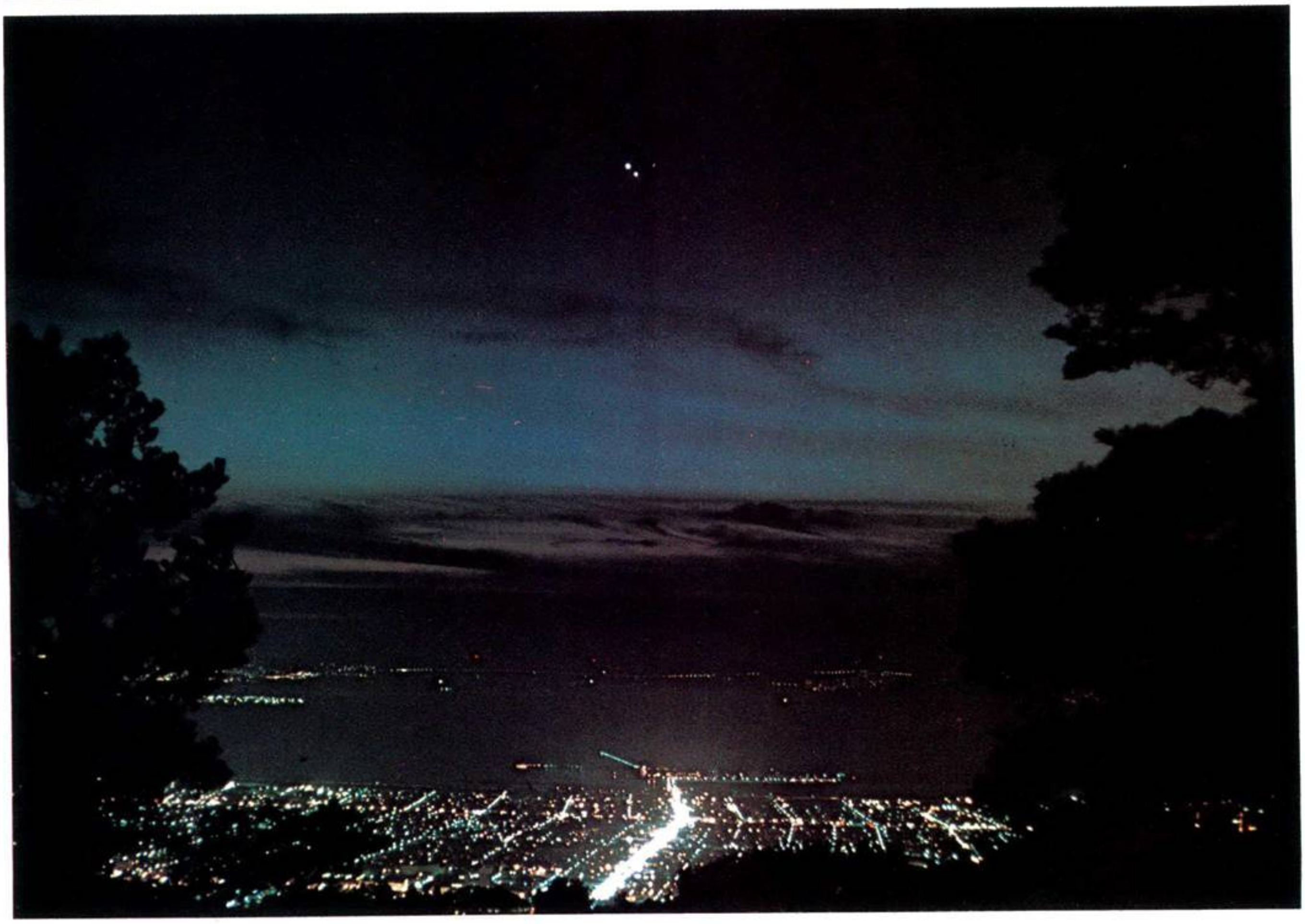
Any telescope will show Venus to be near half phase this month. As the planet's distance from Earth dwindles from 78 to 56 million miles in June, its diameter increases from 20 to 28 seconds of arc. Meanwhile, the planet's phase decreases from 58 percent illuminated on the 1st to 41 percent on the

The Venus-Jupiter conjunction livens a California sunset in this f/2.8, one second exposure at Redondo Beach. A 58mm Minolta SRT-102 and High Speed Ektachrome were used.

Photograph by Stephen C. Reed

The glittering lights of Berkeley, Calif. mirror Venus' and Jupiter's combined brilliance in their rare Feb. 17, 1975 conjunction. The planets hang almost directly over one of a pair of red lights capping the two towers of San Francisco's Golden Gate Bridge. An f/2.8, 50mm Miranda Sensorex camera recorded the sunset spectacle in an eight second exposure on Ektachrome-X film.

Photograph by Jack Stratford



30th. Venus will be exactly 50 percent illuminated on the evening of the 17th. Does the terminator appear exactly straight or does it seem slightly convex or concave in your telescope?

The best time to observe Venus is immediately after sunset — as soon as you can see it — while it is still well above the horizon. Venus can be more easily examined at high power at these times because of its high altitude and because the deep blue sky subdues its dazzling brilliance — an annoyance later in the evening.

Mars and Jupiter

The red planet and the giant planet appear near each other all month in the early morning southeastern sky. They form a particularly striking arrangement on the morning of the 16th when Mars will be barely more than half a degree below (south of) Jupiter. Jupiter — at magnitude -1.8 — outshines +0.8 magnitude Mars nearly 10 to 1 this month, but the two worlds appearing so close will be a sight worth getting up before sunrise to see. If a telescope is employed, both planets will fit into a low power field of view.

In comparing Mars and Jupiter this way, several striking differences become immediately apparent. Mars seems tiny — only 6.5 seconds of arc in diameter — while Jupiter is nearly six times as wide (37.3 seconds in equatorial diameter). This means Jupiter is 30 times larger in terms of visible surface area. Yet the big planet is only 10 times brighter. Hence, Mars has a per-unit surface brightness about three times greater than Jupiter. This fact — not easily compared — should be apparent during this rare time when both worlds are within one telescope eyepiece field.

At the time of conjunction Jupiter will be 491 million miles away compared to Mars' 135 million miles. Both planets will be considerably closer later this year. Mars will be less than half this distance by October and Jupiter will swing 25 percent closer the same month. Detailed telescopic study of both planets should be postponed until later in the year.

Saturn

Now much lower in the western sky than Venus, Saturn is no longer of interest to the telescopic observer. At magnitude +0.4, the distant planet will become difficult to find toward the end of the month. Binocular observers may want to glance at the planet on the evening of the 10th when Saturn will be less than 1/5 degree from third magnitude Delta (δ) Geminorum (see map, page 70, March 1975 for identification of this star).

Mercury

After an excellent period of visibility last month, the innermost planet is too close to the sun for easy observation for all of June.

Neptune

The most distant of the solar system's giant planets comes to opposition — opposite the sun and, therefore, at its nearest point to Earth — on June 1. At 2.72 billion miles away, Neptune certainly is no nearby neighbor; even its feeble light takes over four hours to traverse that distance. A four inch or larger telescope will reveal the distant planet's pale greenish disk only 2.1 seconds of arc in diameter — barely larger than the apparent size of Ganymede, Jupiter's biggest moon.

Neptune, at magnitude 7.7, can be identified in binoculars if you plot its position in a star atlas. Neptune's major satellite Triton is big enough to appear as a 13.6 magnitude star never more than 15 seconds of arc from the planet. A 12 inch telescope should pick it up.

Meteors

On any clear, moonless night of the year, the

The Feb. 13 conjunction of the moon, Venus and Jupiter was an eyecatching event involving the night sky's three brightest objects. This five second High Speed Ektachrome photo was taken from the Heritage School campus in Newnan, Ga.

Photograph by Jim Perkerson

sharp eyed sky watcher will see an average of six or seven meteors per hour. Less than that figure are noticed before midnight and progressively more toward dawn. These meteors are often called *sporadic*, meaning they belong to no particular major meteor shower. But as the study of meteors (*not* known as meteorology!) evolves, evidence is accumulating showing that many of these sporadics are actually members of weak streams of particles related to an existing or disintegrated comet.

Several such marginal showers are predicted for June although they may barely be noticeable. The Herculids, associated with comet Schwassmann-Wachmann 3 (which is due to return in 1979), are an example of this class of weak shower. They are slow moving meteors that seem to radiate from near Beta Bootis during the first week of June.

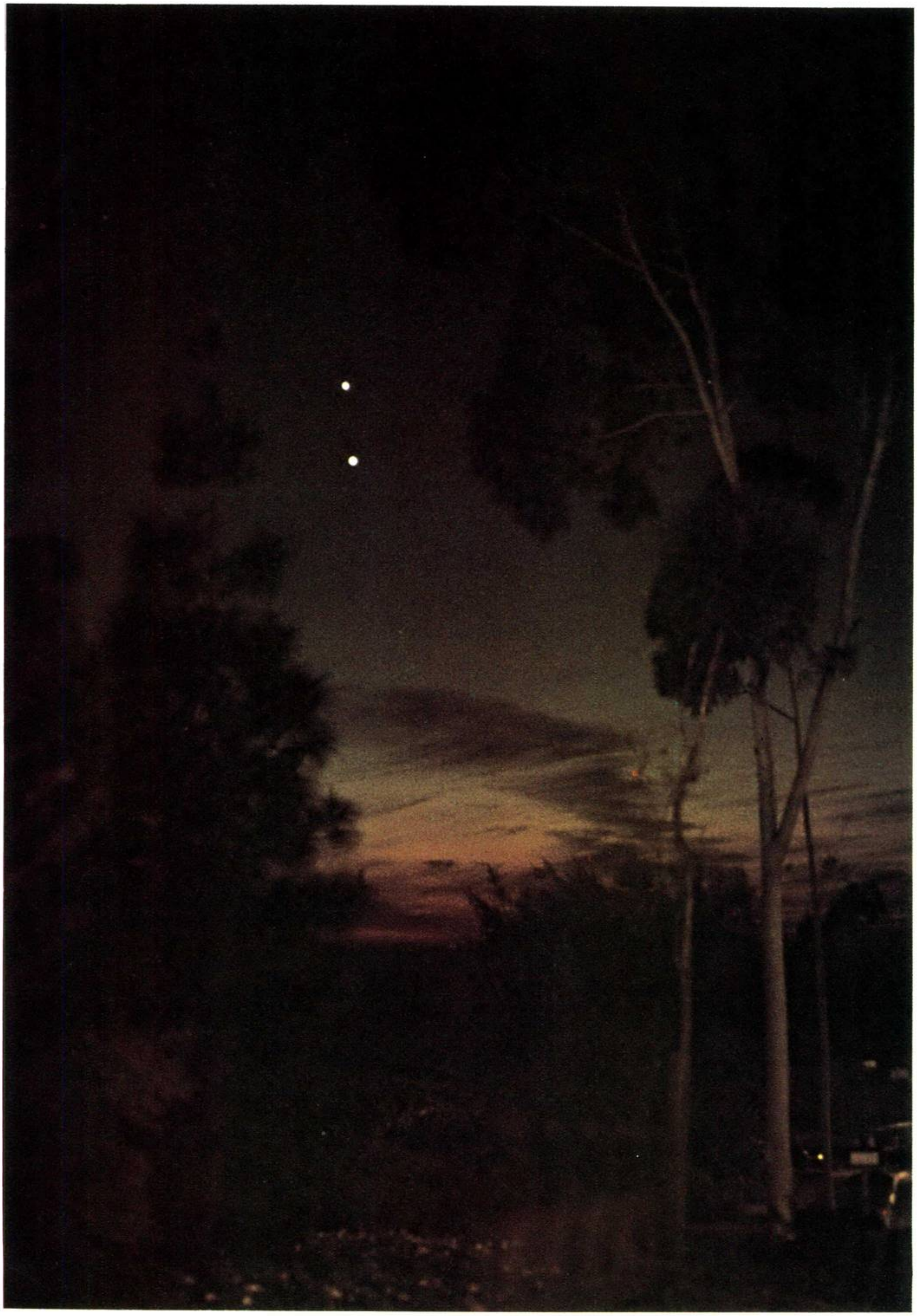
A pair of minishowers is predicted for mid-month. These are the June Lyrids and the June Ophiuchids which radiate from their respective constellations. Although these showers (and there are others like them) are really only for meteor freaks, you may want to casually watch for them between other observing sessions on mild June nights.

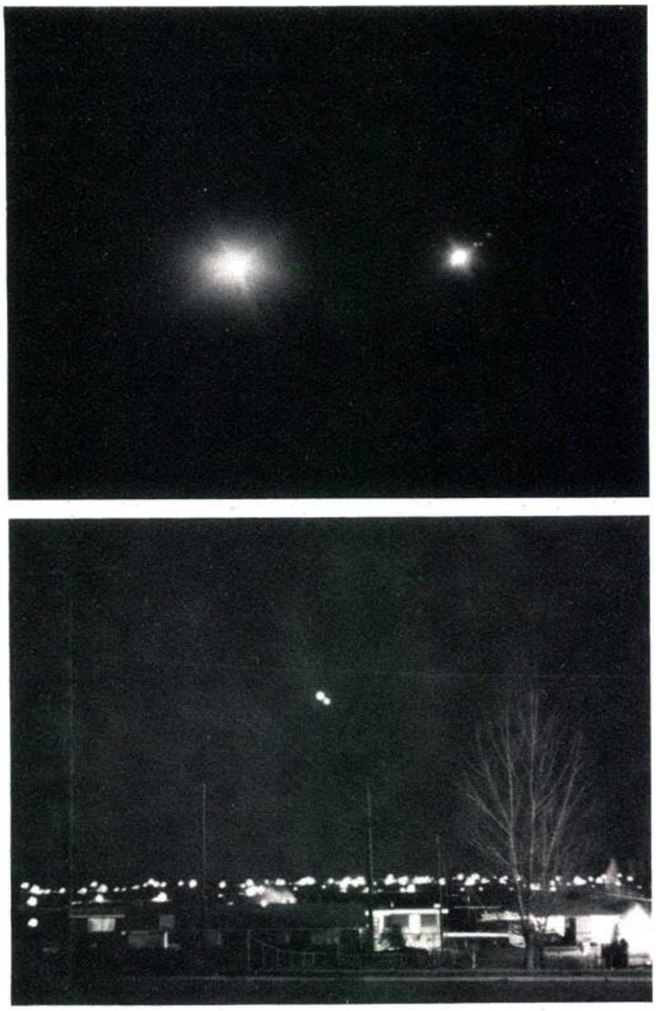
The Draconid meteors, scheduled for the June 27-30 slot, sometimes put on a good show — but the full moon wipes out any chance this year. The Perseids in August are the meteors to prepare for.

Recommended Books and Charts

The beginning sky observer is often puzzled by the plethora of books available on the subject of astronomy. "Which ones will help me learn what's in the sky and how to observe?" is an often asked question. Most astronomy books avoid this aspect of the subject because it is difficult to treat in a comprehensive but clear manner.

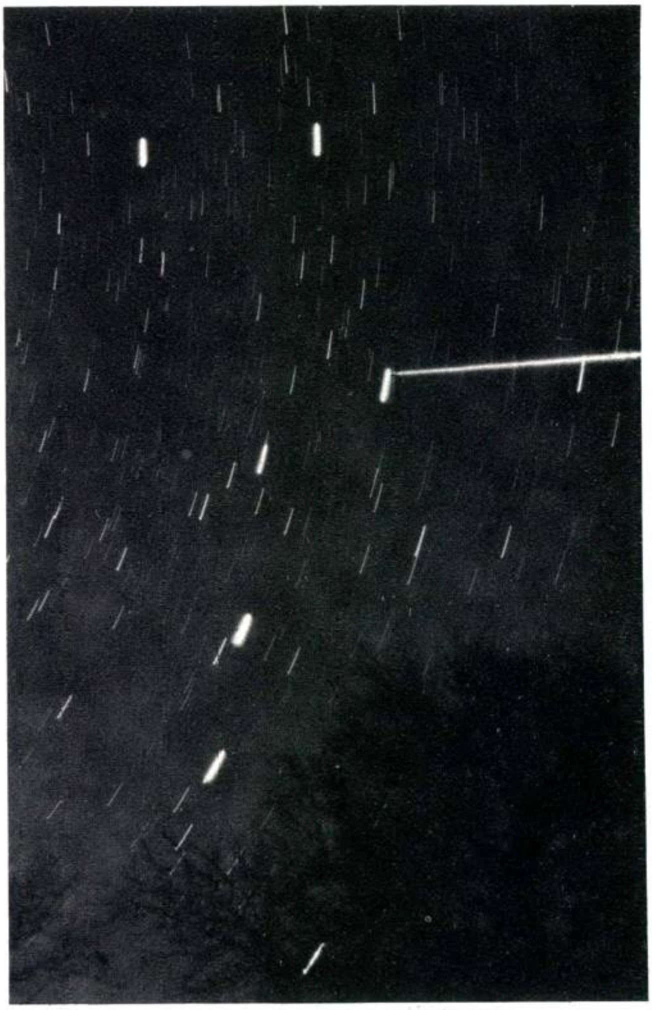
In the various departments of this magazine we try to offer the beginning observer some useful guidelines — especially for the current sky. More general treatment can be found in these books:





Photographs by Dann J. Russell

In the bottom picture, a five second exposure shows Venus and Jupiter just five hours after their rare close conjunction on Feb. 17, 1975. In a three second exposure using 50 power eyepiece projection on an RV-6 Dynascope (top), Jupiter takes on its special character. Clearly visible are the planet's four largest moons. They are — from left to right — Ganymede, Io, Callisto and Europa. Both photos were taken on Tri-X Pan and developed in HC-110 dilution B for 10 minutes.



Photograph by John Bonner

A UFO zapping a disbeliever? A signal from the inhabitants of Gamma Ursae Majoris? The Big Dipper leaking? No, it's a meteor apparently radiating from the bowl of the Big Dipper in a five minute star trail exposure. The photographer opened his camera's shutter an instant after the meteor began streaking across the Dipper. A 55mm f/1.4 Rokkor lens captured the event on Plus-X Pan film. H & W Maximal developer was used in pushing Plus-X's normal ASA 125 sensitivity to ASA 650.

The Sky Observer's Guide by Newton and Margaret Mayall and Jerome Wyckoff (Golden Press, paperback) is the classic beginner's book. Loaded with color illustrations, "how to" advice and clear concise test, this little book gets our highest recommendation. It has more basic observer's information packed into its pages than any other book of its size.

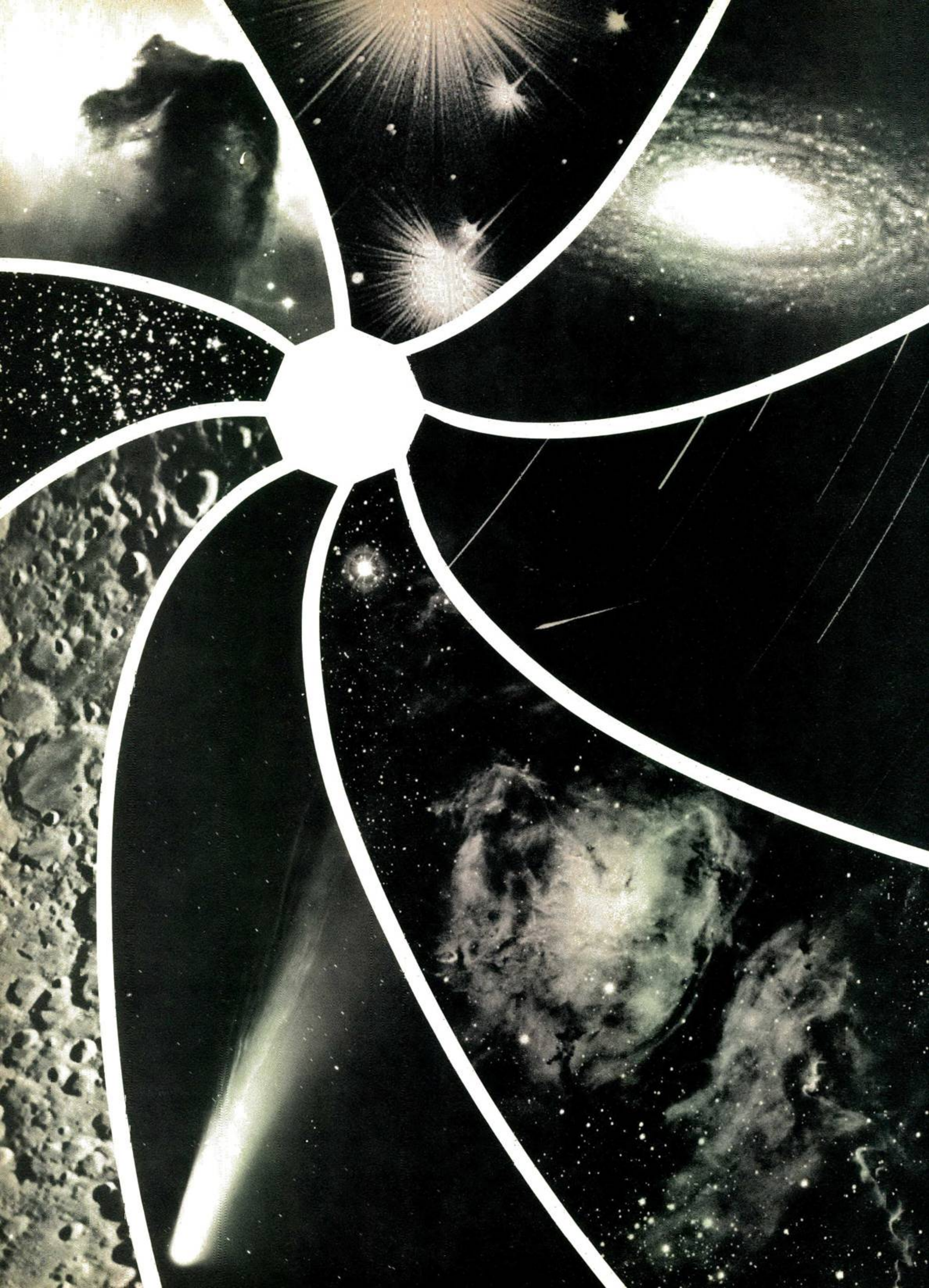
The **Edmund Mag 5 Star Atlas** by Sam Brown (Edmund Scientific, Barrington, N.J. 08007) is without question the best inexpensive star atlas available. At a price of only $1, you can afford to have more than one of these books handy. All stars to magnitude 5.0 are plotted on six clear charts with interesting fainter objects identified as well. About 140 doubles, clusters and nebulae are briefly described. Useful tables include star and constellation pronunciation and star position by right ascension and declination. At the price, this book is an outstanding value.

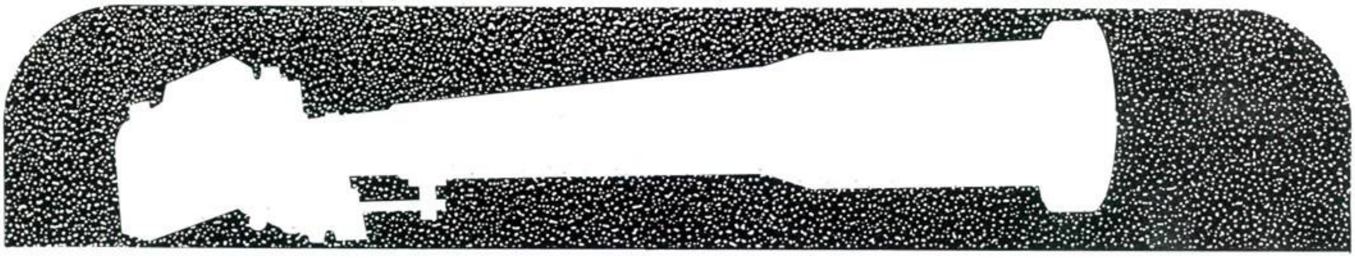
Before the two books mentioned above were available, the best introductory guide was **Field Book of the Skies** by William Tyler Olcott (Putnam, hardcover). Since this masterful compendium was first published nearly half a century ago, it has undergone several revisions by the Mayalls. It is a fine companion to the books just mentioned and the fact that it is still in print means that its popularity has not waned.

Two other excellent beginner's books were previously discussed in Astronomy Reviews. **Guideposts to the Stars** by Leslie C. Peltier (February 1975) and **Whitney's Starfinder** (October 1974) will both get you on the right track to learning the sky in easy steps.

Venus (bottom) closes in on Jupiter in this Feb. 15 photo made just two days before conjunction. The landscape of Rolling Hill Estates, Calif. frames the planetary pair in a five second, f/2 exposure on High Speed Ektachrome pushed to ASA 400.

Photograph by Roger W. Clapp





A Gallery of Celestial Portraits

The constantly changing sky contains a limitless variety of subjects for both the telescopic observer and astrophotographer. Often the celestial target is a dramatic object visually as well as in its photograph — the moon for example. Sometimes a visual disappointment such as a galaxy, which appears like a hazy patch in most telescopes, blossoms into dramatic detail when photographed.

This month we present a gallery of sky photos that represent a broad range of subjects and techniques. (All the techniques we will mention here were described in detail in last month's Photography in Astronomy.) Let's take our photos in groups — each representing a particular method of astrophotography.

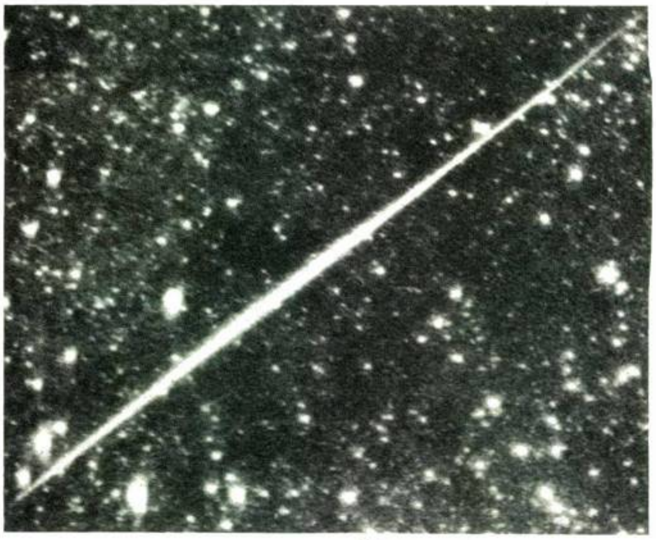
Photos D, E and F were taken using the simplest and most widely used sky photo techniques: stationary camera. No telescope or special mounting was employed — only a rigidly mounted camera. Using a tripod mounted Minolta 102 at f/1.4, Kevin Milani and two other members of the Hibbing (Minn.) Astronomy Club obtained a pleasing star trail portrait (photo F) of the Cassiopeia region by leaving the camera shutter open for 30 minutes. The High Speed Ektachrome film yielded remarkable color saturation in this instance when it was force processed to ASA 400. As encouragement to others who have not yet tried astrophotography, this was Milani's first attempt.

Using the same technique on normally processed High Speed Ektachrome, a 20 second exposure (photo D) reveals a brilliant auroral curtain that lit up the sky on Sept. 15-16, 1974 as seen from Moosehead, Minn. Auroral activity during 1974 was much higher than was expected during near minimum sunspot activity.

Photo E is an interesting double exposure using a stationary Minolta 102 with a 200mm f/3.5 lens and Ektachrome 64 film. Jupiter and Venus were exposed for five seconds. The lens was covered for 45 seconds, and then uncovered so the two planets would leave streaks as they descended toward the horizon. The photo was taken Feb. 18, 1975 from Hibbing, Minn. Other photos of these two planets (closer together) are displayed in Sky Almanac.

An interesting "double capture" of a meteor (photos A and B) was accomplished by two members of an observing team located at Keystone Junior College Observatory near Keystone, Pa. The meteor was a zero magnitude Perseid from last year's (Aug. 11-12) shower. Six cameras were gangmounted on a driven equatorial mount. Photo B was taken on Kodak Tri-X film with a 28mm f/2.8 wide-angle lens. Developed in Ethol FG-7 at 1 to 15 dilution for seven minutes at 72 degrees, the film was pushed to ASA 1600. Photo A is a Nikon 50mm f/1.4 shot on Kodak 2475 Recording film and double developed in Ethol FG-7 with nine percent sodium sulfite solution for 15 minutes at 72 degrees. Both photos were printed on F-4 contrast paper. The bright star near the metor's train is Epsilon Cephei.

Ⓐ Photograph by John Sabia



Ⓑ Photograph by Jerry Zawislak

These two meteor photos suggest several projects: (a) simultaneous performance testing of various films and cameras, and (b) altitude estimates of meteors from photos taken at two locations tens of miles apart. The second suggestion is best accomplished by having two gangs of guided cameras at different sites (more about this in a later issue).

Venus has been involved in two spectacular affairs with other celestial bodies in the past year — the Venus-Jupiter conjunction (which is well illustrated in this issue) and the occultation of Venus by the moon on July 17, 1974. The October 1974 issue had several photos of the occultation but we decided to include one more excellent example — photo G. This is a one inch eyepiece projection one second guided exposure on Fujichrome R-100 film, using the seven inch refractor at Brooklyn College Observatory.

As films and astrophotographic techniques improve, the detail seen in amateur photos gradually increases year by year. Photo N is an example of Jovian detail secured through a 12-1/2 inch home built Newtonian reflector on Kodak High Contrast Copy film exposed for four seconds. Taken on Aug. 26, 1974, this photo clearly shows cloud detail in the two major equatorial belts as well as the prominent Great Red Spot. Planetary photos such as this — and lunar portraits too — require excellent seeing as well as good equipment and some experience on the part of the photographer.

Many years of experience and hundreds of trial photos are needed to reach the high quality achieved by Howard Zeh as represented in the lunar photos K and M. The first of these shows the mighty 140 mile diameter lunar crater Clavius that boasts hundreds of smaller craters within its three mile

Ⓒ Celestron Pacific Photograph

ⒹPhotograph by David Anderson

Ⓔ Photograph by Kevin Milani

Ⓕ Photograph by Kevin Milani

high ramparts. This picture is a 3/4 second shot on Kodak Plus-X film through an eight inch home built f/8 Newtonian reflector using eyepiece projection. Zeh's full moon shot is a 1/250 second exposure on VTE film with a Nikon camera body. Achieving good definition in the subtle contrast of the full moon is notoriously difficult.

The Orion nebula, photo L , is the favorite deep sky object for astrophotographers. The four stars of the Trapezium are just barely resolved in this eight inch Celestron prime focus photograph of the Orion nebula. The nebula is usually more heavily exposed in order to show the full sweep of the filamentary detail. This particular density reveals the embedded stars quite well. The 30 minute guided exposure on Tri-X was developed 4-1/2 minutes in Acufine at 73 degrees. Some dodging was necessary to reveal the Trapezium on the print. Michael Moe reports, "This photograph was made Jan. 13, 1975 in my front yard within 25 yards of a mercury vapor street lamp. However, seeing and visibility were excellent."

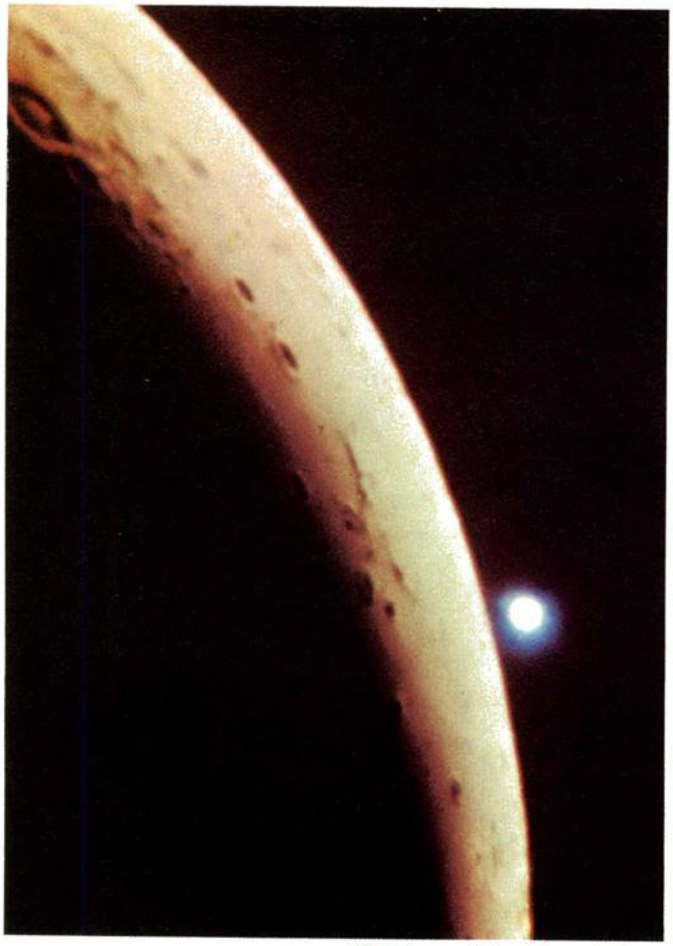
Similar in difficulty to the Orion nebula shot, but using a slight variation on a harder subject, is the portrait of M-67, an open cluster of stars in Cancer (photo J). This 30 minute GAF 200 exposure was taken through a six inch f/4.5 Newtonian telescope strapped piggyback on a larger portable Newtonian. The clean central images in this photo attest to precision guiding techniques. Note the slightly elongated images at the outer edge of the field caused by unavoidable coma in rich field telescopes. This type of telescope with its advantages and disadvantages is discussed in this month's Equipment Alas.

A rather sophisticated piece of equipment — a 14 inch Celestron Schmidt camera — was used for photo C, a portrait of the spiral galaxy M-101 and its surroundings. The 15 minute Fujichrome R-100 photo contains the images of at least five other galaxies in this four square degree segment of Ursa Major.

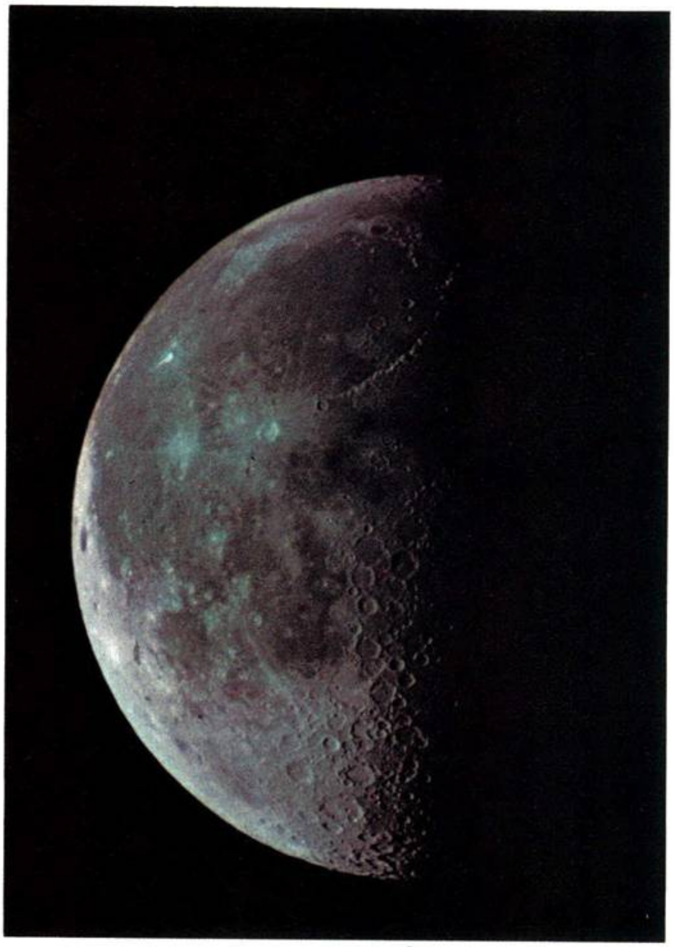
Star Dome Photo Data

Several readers have inquired about the equipment and techniques used for the photos in our Star Dome Close-Up area maps on page 73 in each issue. They are all piggyback photos, but are taken with a variety of cameras. The January and March photos by Leo Henzl were 15 minute Fujichrome R-100 shots through a Canon F-1. The f/1.4 lens was set at f/2.8. Henzl's May photo was taken with the same setup except the film was Kodak 103aF. In this issue, the Henzl shot is an 18 minute exposure on High Speed Ektachrome at f/3.5 on a Yashica twin lens reflex camera.

The photos by John Sanford in the February



Ⓖ Photograph by Anthony A. Sasso



Ⓗ Photograph by F.E. Morrell

Ⓙ Photograph by Robert Provin

Ⓚ Photograph by Howard F. Zeh

and April issues were both taken on Fujichrome R-100 processed to ASA 200. The Orion portrait, a 30 minute exposure at f/2.0, was taken with a Fujica 701 camera equipped with a 50mm f/1.8 lens. The Big Dipper photo (April issue) is a section of a 35mm lens shot using a Nikon F camera. The f/2.8 lens was set at 3.5.

Photo Submissions

The editors and staff of ASTRONOMY are delighted by the enthusiastic response of our readers as demonstrated by the hundreds of photos received in recent months. We will try to use as many as possible both here and in Sky Almanac. If you have submitted a photo and haven't heard from us yet — don't despair. We may find a place for it in an upcoming issue.

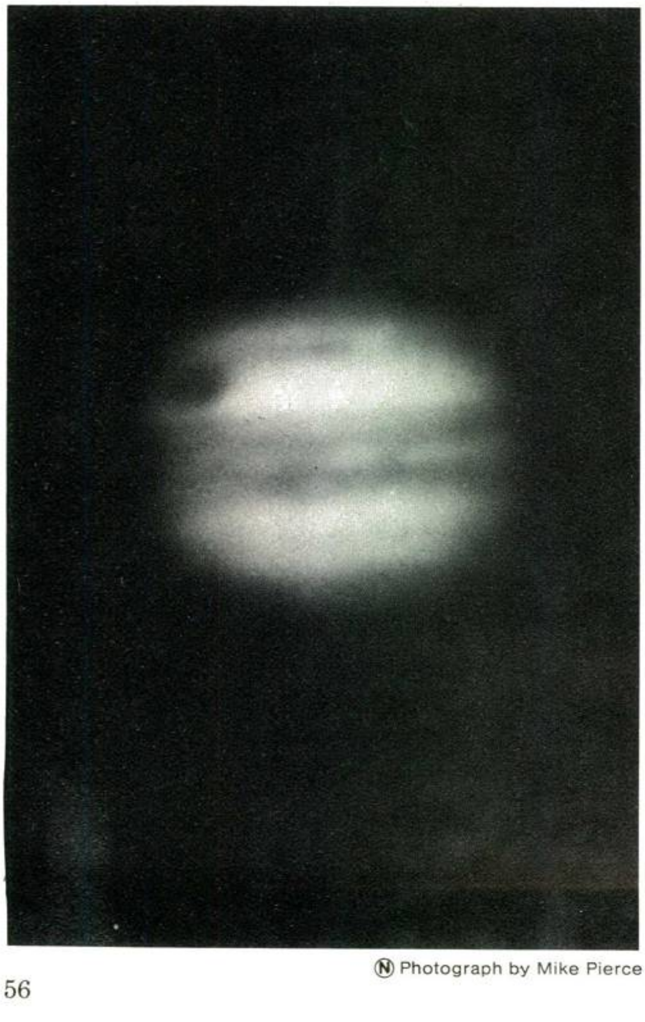
If you have a photo you think is worthy of publication, or if you happen to take one in the future, here are some submission guidelines:

Make sure the star images are crisp and round. Lens aberrations or inaccuarte guiding are difficult to avoid but if they are, your photo has a much higher chance of being published. Do not send negatives. Slides or prints (preferably not the silky finish type) are both okay for color. For black and white, send prints only. Do not write or type on the back of photos in a manner that will make the imprints visible from the other side.

Photos taken with modest equipment are

Ⓛ Photograph by Michael Moe

Ⓜ Photograph by Howard F. Zeh



Ⓝ Photograph by Mike Pierce

welcome if they are good efforts for the size of telescope used. Observatory quality work can be done with remarkably inexpensive setups. And be sure to tell us what equipment you used for the photo. What size and focal ratio is the telescope? What make of telescope is it, or is it home built? What type and make of camera was used? How long was the exposure? What type of film was used and how was it processed? When and where was the photo taken? Your photo has more value if you provide all this information — and it has a better chance of being published.

Portraits of seldom observed objects are, of course, scarce. If you get a good one of, say, NGC-3242, then you will be one of only a handful of astrophotographers who have. Piggyback 50mm guided photos of sky areas are needed as well. How about the Sagitta-Delphinus-Aquila area? Can you get all of Pegasus in a frame? Schmidt camera or 135mm shots of selected sky areas are also needed for our files — both black and white and color.

All this does not go unrewarded. Upon publication you will be paid $10 for color or $7.50 for black and white photos used in ASTRONOMY. Be sure to include all the information requested above with your photo submission. Send photos to The Editors, ASTRONOMY Magazine, 757 N. Broadway, Suite 204, Milwaukee, WI 53202.

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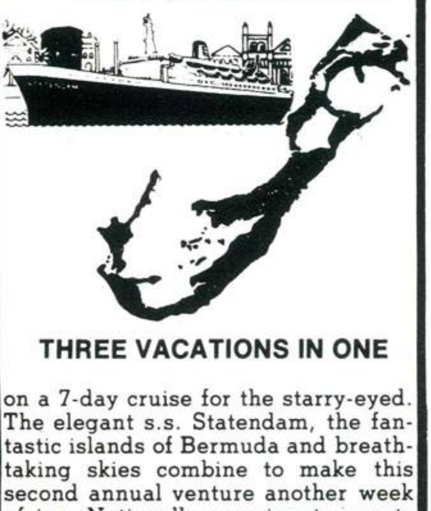

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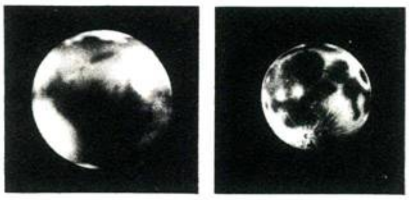

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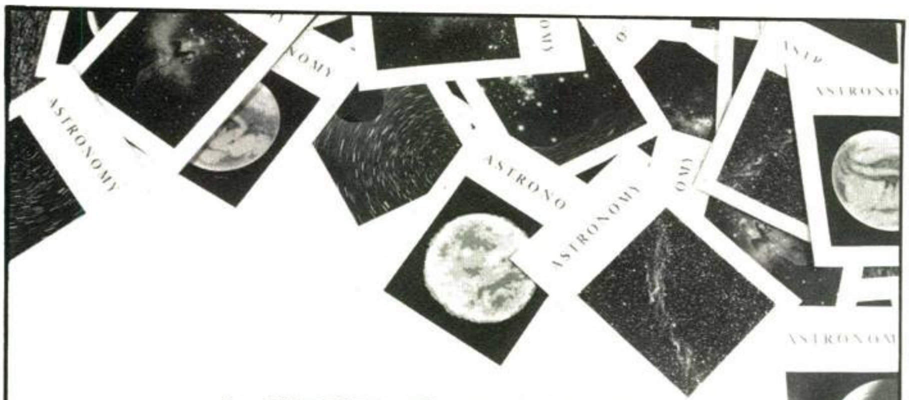

ASTRONOMY

Guide to Back Issues

Many readers continue to ask about the availability of ASTRONOMY back issues, but the majority blindly send us an order requesting issues we no longer have. For example, the October 1973 issue has been sold out for at least six months.

The following guide, which will be changed monthly, is designed to give you the most up-to-date information on the status of back issues. While they last, back issues are available for the cover price of $1.50 each (price includes postage).

When ordering, please clearly state quantity, volume, number, month and year for each issue (first issue was August 1973), and **include payment with your request.** If issues ordered are no longer available, unless you instruct us to forward a refund or substitute issues, we will automatically extend your subscription appropriately.

Vol. 1, No. 1 - August 1973	**Available**	**Vol. 2, No. 8 - August 1974**	**Depleted**
Vol. 1, No. 2 - September 1973	**Depleted**	**Vol. 2, No. 9 - September 1974**	**Available**
Vol. 1, No. 3 - October 1973	**Depleted**	**Vol. 2, No. 10 - October 1974**	**Short supply**
Vol. 1, No. 4 - November 1973	**Depleted**	**Vol. 2, No. 11 - November 1974**	**Available**
Vol. 1, No. 5 - December 1973	**Depleted**	**Vol. 2, No. 12 - December 1974**	**Short supply**
Vol. 2, No. 1 - January 1974	**Depleted**	**Vol. 3, No. 1 - January 1975**	**Available**
Vol. 2, No. 2 - February 1974	**Depleted**	**Vol. 3, No. 2 - February 1975**	**Short supply**
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Vol. 2, No. 6 - June 1974	**Available**	**Vol. 3, No. 6 - June 1975**	**Available**
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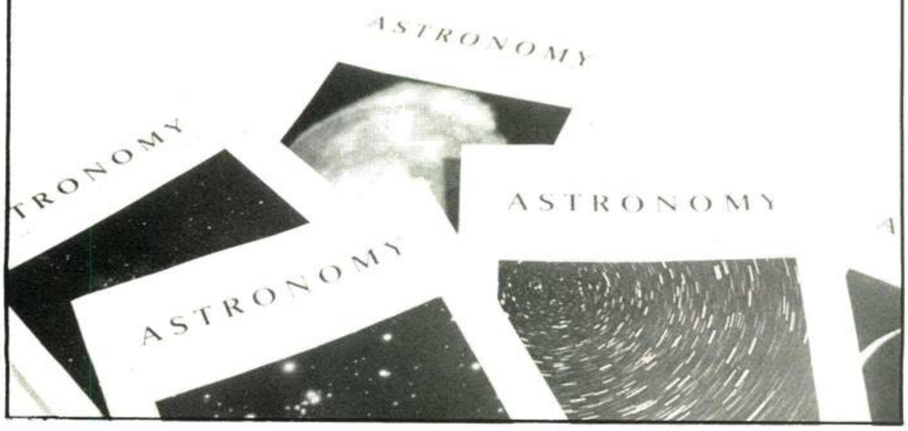

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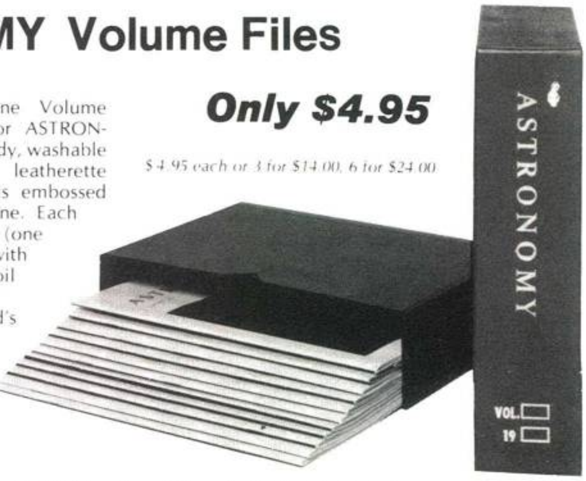

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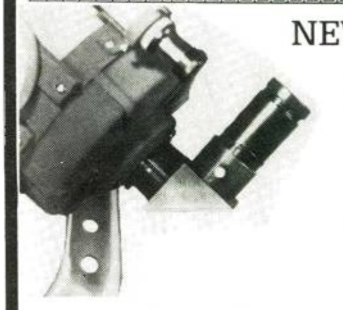

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ASTRO-NEWS

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Mariner 10 Flyby Confirms Mercury's Magnetic Field

Mariner 10's encounter with Mercury showed that the magnetic field unquestionably belongs to the planet and is not the result of the solar wind in a complex interaction with Mercury.

Unlike the moon, which simply absorbs the solar wind as it impacts the surface, Mercury deflects the solar wind plasma around it by a magnetic field — although that field is not strong enough to trap particles into radiation belts. The field of Mercury can be explained in terms of a scaled down Earth's field. Its direction, too, is the same as Earth's field.

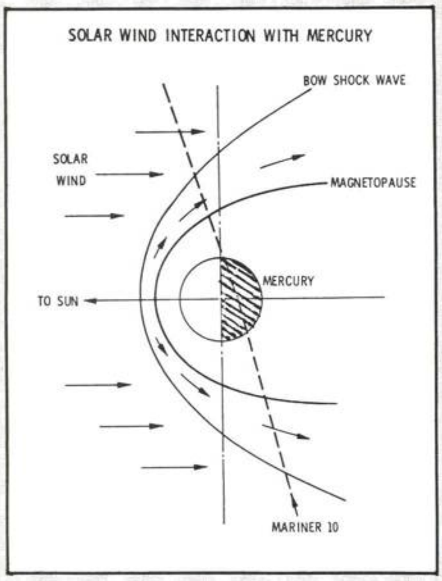
Based on the data received during the first encounter, Norman F. Ness (of NASA's Goddard Space Flight Center and principal investigator for the magnetic field experiment) predicted the magnetic characteristics of the third flyby assuming a dipole field intrinsic to Mercury. The actual encounter fitted the model almost exactly.

In addition, the solar wind electron measurement and the observations of charged particles of high energy (relativistic electrons and protons) also confirmed that the field of Mercury behaves just as would be expected of an intrinsic field. "The composite results of the magnetic field measurements establish unequivocally that the planet Mercury is one of the few magnetized terrestrial planets in our solar system," Ness comments. "The origin of the magnetic field is definitely associated with the planetary interior."

Now the question asked is whether Mercury's field arises from permanently magnetized crustal rocks or is an active dynamo mechanism in a still-fluid core.

If the field resulted from a permanently magnetized planet, this would require a very special set of circumstances for the formation and subsequent evolution of Mercury. For example, one speculation is that there might have been a very strong interplanetary field at the time Mercury solidified. Another is that there might have been a period when Mercury rotated rapidly and did possess a dynamo field which somehow became trapped in the surface rocks as the dynamo ran down. Both speculations introduce unnecessary complexities.

A current dynamo field explanation, however, seems the most simple and plausible at the moment. In this theory, the field is generated by a system of electrical currents circulating in the planetary interior. But the question remains: "What is the energy source to drive the dynamo? It could be caused by convective circulations due to heat released by radioactive decay of isotopes of uranium, potassium and thorium, or it could be settling of the heavier elements such as iron and nickel to the planetary core. Such explanations must assume that the core of Mercury is still hot and is also still liquid.



Another possibility for the energy source is core precession arising from different rotation rates and rotational axes between the core of Mercury and its mantle. Some light may be thrown on which is the more likely explanation for Mercury's field when Mariner 10 trajectory data have been fully analyzed in the coming months. Excellent uninterrupted Doppler data were obtained by the Deep Space Network stations. These data are expected to provide information on the distribution of mass within the interior of Mercury.

Matter Observed in Radio Source

Astronomers have for the first time linked optical activity within a galaxy to its nearby radio region. This discovery came during routine testing of the new 158 inch telescope at Cerro Tololo Inter-American Observatory in Chile — the largest telescope in the southern hemisphere.

The instrument's color photograph of radio galaxy NGC-5128, or Centaurus A (appearing on page 22), reveals previously undetected filaments of gas and dust and groups of stars. Radiating away from the galaxy's center, these streamerlike filaments extend into one of the giant lobes of radio energy accompanying Centaurus A.

Near this radio "bubble", starlike clusters also appear. Follow-up observations using the observatory's 60 inch telescope indicate that the stars are young and extremely hot.

Cerro Tololo's findings should provide new clues about energetic events occurring in Centaurus A, one of the most puzzling extragalactic objects now confronting astronomers. Visually, it appears as a glowing, fuzzy disk bisected by a dark lane of matter. Some experts think that the dark matter identifies a spiral galaxy, colliding with a bright elliptical galaxy. Others pro-

Matter *continued on page 66*

Mariner 10 Yields Few Photos

After six months of tricky solar "sailing" while Mercury made two orbits of the sun, Mariner 10 swung past the innermost planet for the third time at 6:39 p.m. EDT, March 16, 1975. The flight plan for this encounter was for a pass over the dark side within 130 miles of the planet's heavily cratered surface; the objective was to gain more information about the unexpected magnetic field of Mercury discovered at the first encounter one year earlier. Final readings revealed the actual encounter was 190 miles from Mercury at 70 degrees north latitude.

Mariner 10 lived up to its reputation as a "neurotic" spacecraft as the day of encounter neared. Following the loss of most of the reserves of maneuvering gas very early in the mission (when the roll gyro system went into unexplained oscillations during roll calibration maneuvers), project engineers devised a way to "sail" the spacecraft to subsequent planetary encounters. By using the sun's radiation pressure on the solar panels and the high gain antenna to control the rolling of the spacecraft, the use of the roll gyro was kept at a minimum.

For months before the third encounter, Mariner 10 had been in a free-rolling mode; that is, the project engineers let the spacecraft roll while keeping tabs on its orientation by observing the passage of stars through the field of the Canopus tracker, and by measuring the changes in amplitude of the radio signal received at Earth from the omnidirectional antenna of the spacecraft. This antenna is not truly omnidirectional, but it possesses a characteristic radiation pattern which could be observed. (The antenna is actually nearly "blind" at one particular orientation.)

As Mariner 10 approached its final rendezvous with Mercury, the roll rate of the spacecraft had a period of about 60 hours. Thus Canopus came through the tracker's view only once every 2-1/2 days. The task facing mission controllers was to let Mariner continue rolling freely as close as possible to encounter, but to stop the roll in good time for the encounter. The roll could not be stopped too far ahead because the spacecraft might be distracted by bright particles or spill its final few millipounds of nitrogen gas in an uncommanded gyro oscillation.

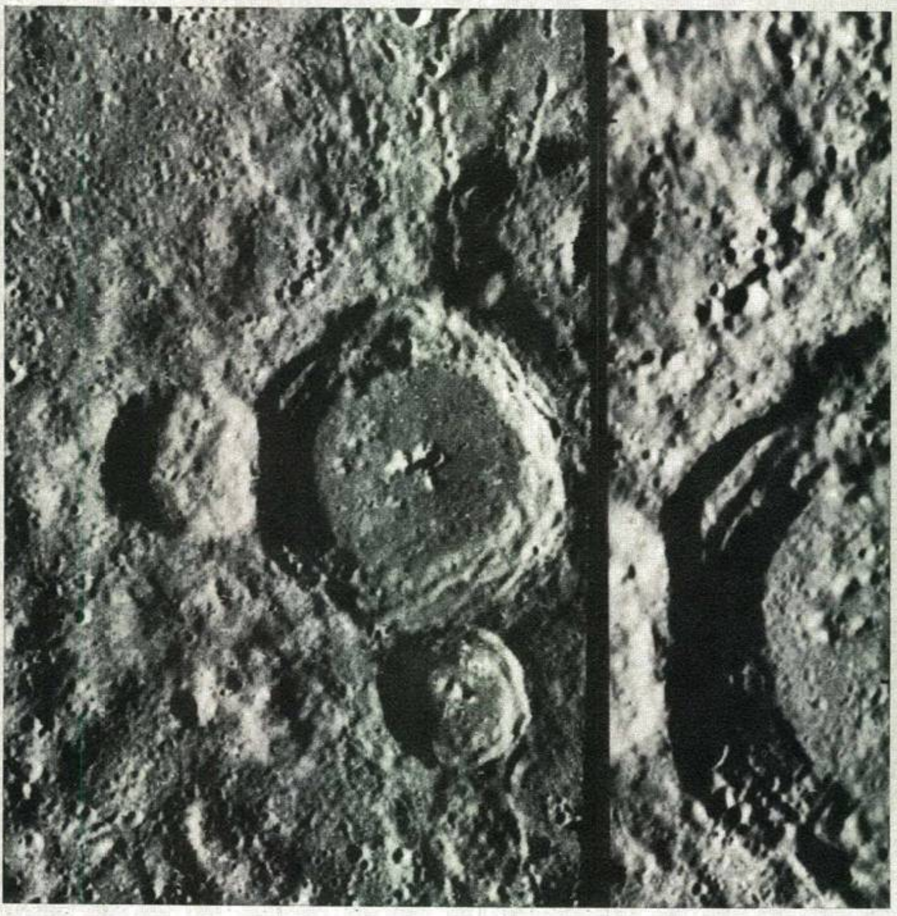
However, if a first attempt to acquire Canopus had been delayed, the 2-1/2 day roll period did not allow for a failure to acquire Canopus and then provide time to try again. Attempts were made to speed up the roll by pulling in the high gain antenna, like an ice skater tucking in her arms to spin faster.

On Thursday (March 13) before the encounter, controllers thought that the spacecraft had rolled by Canopus. It was actually a false alarm; a distracting particle went by just at the wrong time, and since the telemetry channel for stellar magnitude had been inoperative for some time, the bright particle was mistaken for Canopus. The result was that the spacecraft became oriented to an incorrect position at which the "blind" point of the low gain antenna's radiation pattern was directed toward Earth. With just over three days to go, communications ended between Mariner and Earth's ground stations: Mariner was silent.

Now the problem was to command the spacecraft to change its orientation. Otherwise, it would fly by Mercury as pre-programmed and send all its information on a high gain antenna beam pointed away from Earth. Goldstone's big antenna was needed to get the message to the spacecraft. And failing that, Canberra's big antenna could next be tried, followed by the antenna in Spain.

Another problem loomed: Helios — an unmanned craft probing the space between Mercury and the sun — was approaching perihelion, and most of the big antennas were already committed to serving that spacecraft. Rapid telephone calls from Pasadena to Germany obtained some of the time allocated to Helios. Finally a command was pushed to the spacecraft from Madrid, and by 3:00 a.m. Saturday — 1-1/2 days before encounter — the real Canopus was acquired. Mariner 10 was successfully oriented for its third encounter.

But the problems were far from over. Although the magnetic field, solar wind, and energetic particle data expected of this encounter were all successfully received, the encounter proved



NASA Photographs

One year separates these two views of Mercury's surface. The left image was taken March 29, 1974 when the Mariner 10 space probe was 20,650 miles away from this tiny, sunbaked planet. The picture on the right was transmitted March 17, 1975 as Mariner 10 flew by Mercury for a third and final visit. Note the terracing inside the large crater and erosion on the crater's walls by secondary impacts from a smaller nearby crater. Of course, over just one year's duration, no surface changes are apparent on this seemingly static, moonlike world.

somewhat disappointing from the imaging standpoint.

First, the low-noise receiver of the Canberra station failed. It could not be tested thoroughly in advance because of Helios commitments. A leak had developed in the maser which could not be fixed in time for Mariner 10's encounter. So the imaging data had to be received at the low bit rate of 22,000 bits per second, compared with the hoped-for 117,000 bits as was used at earlier encounters. Because the tape recorder on board Mariner had failed long ago, there was no possibility of storing images on the spacecraft for later transmission at the low bit rate. The images had to be sent to Earth in real time.

At the low bit rate available without the Canberra maser, this meant that only 1/4 of each picture could be returned; the rest were lost forever. In addition, the low bit rate only allowed six bits instead of eight bits digitization — thereby degrading the quality of the 1/4 frame that was received.

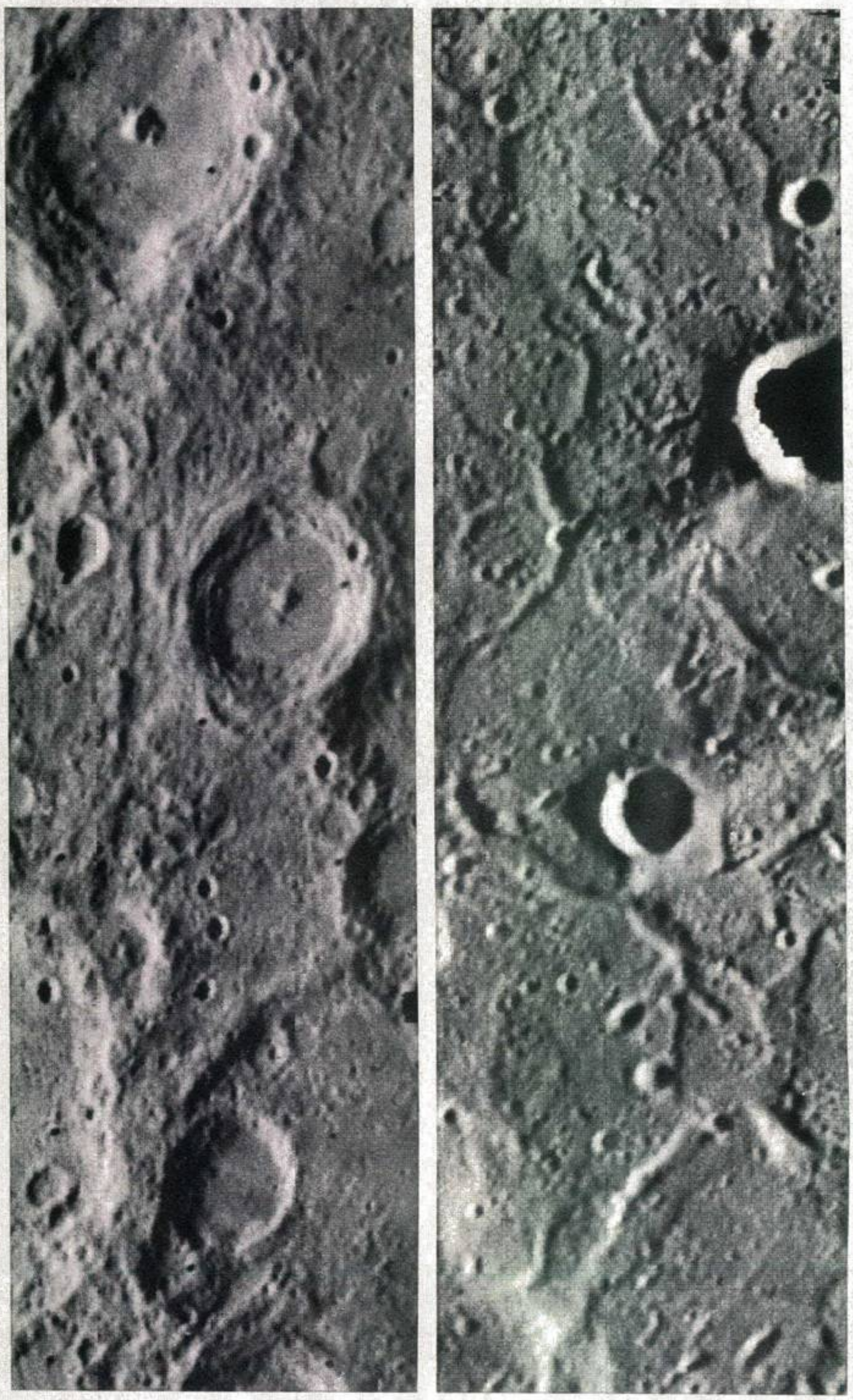
The pictures might have been saved by reconfiguring the spacecraft to send the pictures to Goldstone at high bit rate, since the spacecraft was also above the horizon at Goldstone at the time of the encounter and Goldstone had an operating maser. Unfortunately, the transmitter at Goldstone was inoperable so it was impossible to send a command to reconfigure the spacecraft.

So the reduced area of imaging had to be accepted. Fortunately, the imaging program had been selected to look in detail at those interesting areas of the planet observed in the earlier wide coverage of the first two encounters — areas such as the floor of Caloris basin and the jumbled terrain. So the imaging experiment partially attained its objectives in getting detailed coverage of specific areas of interest.

However, the third encounter approached closer to Mercury than the other two and offered an opportunity to get high resolution pictures of the surface — an expected 150 foot resolution. But because of this close approach, a decision was made to shorten exposures to avoid smear. With the high rate of bit transmission this could have worked successfully, but with the reduced rate it did not. The least significant bits that were chopped off in the reduction of eight to six bit digitization were the bits that might have given some details in the underexposed terminator regions. As it was, all these close-in pictures were hopelessly underexposed to the point of blankness. (While the computer program might have been able to compensate for smear, it can do nothing to convert zeros of intensity level into something meaningful.)

Nevertheless, in the context of the whole mission, the imaging of Mercury has been tremendously successful and has provided a look at the innermost planet which is now allowing planetologists to take a completely new look at the formation of the planets of the inner solar system and the origin of the huge missiles that pock-marked their surfaces. At least five distinct epochs of planet building now seem to be indicated by examination of the cratered surfaces of the moon, Mars and Mercury.

Additionally, the discovery of Mercury's magnetic field has raised questions about the validity of accepted theories of planetary fields in general, since the dynamo theory has traditionally suggested that only quickly rotating planets would have significant magnetic fields.



NASA Photographs

Two views of Mercury shortly preceding and following Mariner 10's closest encounter on March 17, 1975 show a desolate, heavily cratered landscape. In the picture on the left, taken from 40,000 miles, predominant craters are about 20 miles in diameter. At a range of only 11,800 miles in the photo on the right, fractured and rumpled plains in Mercury's Caloris Basin appear in exceptional detail. Black spikes along the frame's edges are locations where image data is missing.

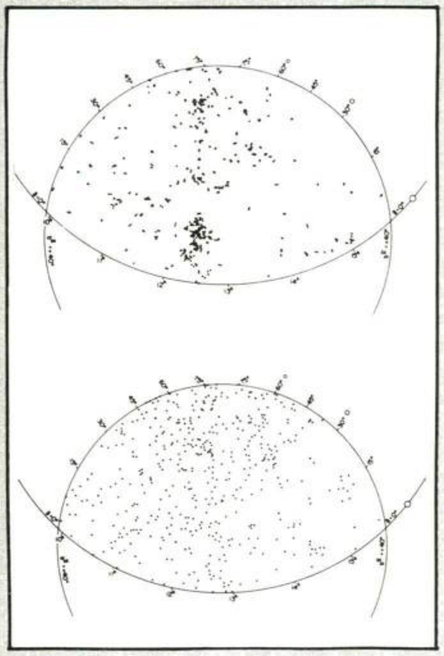
Lone Galaxies Discovered

The universe appears to be split into two distinctly different distributions of galaxies — those galaxies that travel in groups or clusters, and those galaxies that are "loners". The loners make up a smoothly spread field of galaxies surrounding the galaxy clusters.

This surprisingly uniform galaxy background was accidentally discovered during a cataloging of galaxy clusters by Caltech astronomer Edwin Turner and J. Richard Gott of the Institute of Astronomy in Cambridge, England.

"We were quite amazed," says Turner. "It took us close to a month to convince ourselves that we were seeing a real effect and not some sort of optical illusion."

The problem is that no current models of the universe predict such structuring. For example, all versions of the big bang theory favor a universe composed entirely of clumps of galaxies. The basic big bang model hypothesizes that clusters condensed out of gravitational instabilities in the expanding "sea" of hydrogen that characterized the universe soon after its explosive birth.



A recent plotting of galaxy clusters uncovers two distinct distributions of galaxies existing in the universe. In the top stereographic map of a section of the sky (centered on the north celestial pole), both small and large scale clustering is evident in 623 of 1,088 galaxies sampled. The remaining 465 galaxies, separately plotted in the bottom map of the same region, form a remarkably smooth scattering among the clusters. No current models of the universe predict such an effect.

In fact, present cosmological theories imply that producing a smooth background of galaxies is extemely difficult. "We don't know why half of the galaxies should 'feel' each other's gravitational attraction and fall into clusters and why the other half should apparently ignore gravitational attraction and just sit there in space," explains Turner.

At least for now, it seems that this smooth distribution does not favor one theory of creation over another, nor does it apparently offer strong evidence for settling the puzzle over whether the universe will continue expanding forever (known as a gravitationally *open* universe) or someday contract under its own gravitation (*closed* universe). However, Turner points out that gravitational instabilities induced by a closed universe would make this smooth background unstable.

Turner and Gott started out sampling 1,088 bright (above 14th magnitude) galaxies listed in a catalog compiled in the 1960s. They defined a galaxy as belonging to a cluster if a neighbor galaxy lay within .75 degrees. Roughly 60 percent of the sample (623 galaxies) fit this criterion; the remaining 465 galaxies are single. When these lone galaxies are mapped out they form a strikingly smooth and uniform background.

To rule out the possibility of this phenomenon being an optical illusion, the researchers conducted a separate statistical analysis. It confirms that two distinct populations of galaxies exist out there.

In 1934, Edwin P. Hubble (famous for his discovery that all galaxies are receding from us) hypothesized that galaxies were just randomly scattered through space, and that some formed clusters and others did not. "In a sense, it's sort of a step backwards to that old point of view," says Turner. "But this distribution is the first strong evidence that the old view has been right and the new view wrong — although I don't think anyone ever had a *theoretical* understanding of why there should be a galaxy background."

This discovery is still too new and unexpected for astronomers to fully assess what impact it will have on their understanding of the universe's shape, structure and evolution. After additional study, the new data might be able to mesh into the current cosmological view or instead force a fundamental reworking of our concepts of creation. Turner estimates that it will require at least one year of interpretation before he can make any final guesses.

Matter *continued from page 63*

pose that Centaurus A is a single galaxy exploding at the center.

Strong evidence for something catastrophic occurring there comes from radio observations of two huge lobes of intense energy on either side of NGC-5128. Their existence implies that great quantities of matter were blasted out either side of Centaurus A's visible core.

This apparent link between optical and radio structures in Centaurus A marks the first important finding by the 158 inch instrument since it began test operations in last October. Additional exciting deep space discoveries likely await this first major southern sky observatory.

IMP Detects Radio Bursts From Saturn

In this time of concern over sound pollution, even the solar system seems noisier — at least to radio ears. During the past year an IMP satellite (Interplanetary Monitoring Platform) has detected 11 strong, one MHz radio bursts from the direction of Saturn.

Like Jupiter — the only planetary radio source other than Earth — Saturn's behavior likely indicates the presence of radiation belts shaped by a powerful magnetic field. Since Saturn's peak radio energy is 1/8 the strength of Jupiter's, the ringed planet's magnetic field is correspondingly 1/8 as intense. Probably whirling through the field are electrons and protons trapped from the solar wind and energized into emitting radio static.

Why the energy comes in bursts remains a mystery. It seems synchronized with Saturn's dizzying 10 hour daily rotation. Some astronomers suspect that radio pulses may be generated by particles raining into Saturn's upper atmosphere. There, rapidly increasing collisions with other particles would trigger an explosion of radio energy analogous to the way a laser amplifies light into an intense beam.

Jupiter also releases radio blasts apparently in step with its rotation. According to one theory, Jupiter's closest moon (Io) may induce powerful electric currents as it speeds through radiation belts, triggering incredibly strong lightning discharges in the Jovian atmosphere. However, the results of the recent Pioneer 10 and 11 flybys of Jupiter indicate that the Io interaction is probably more complex than previously believed.

Radio Astronomy Explorer Satellite 2, now orbiting the moon, will hopefully confirm the Saturn discovery.

STAR DOME

JUNE

During the winter, the constellations were our companions as we trudged home from work or late classes at school. But now on lazy summer evenings the stars seem to take their time about coming out. Any worthwhile stargazing is going to have to wait until after 9:00 p.m. on these longest days of the year, but there's plenty of time to watch the early summer sky show unfold on these warm evenings.

Arcturus (arc-TOUR-us), among the first superstars of the evening, appears almost directly overhead as darkness falls. The fourth brightest star in the northern hemisphere, yellow-orange Arcturus is closely rivaled by Vega, a brilliant blue-white star rising in the northeast. Another blue-white star, Spica (SPY-ka), hangs halfway between Arcturus and the southern horizon. Gleaming Regulus beckons in the western sky as the base of a backwards question mark identifying the constellation Leo the lion. As the night grows darker, Denebola (de-NEB-o-la) -to the left of Regulus- draws attention. This second magnitude star marks the tip of the lion's tail.

Striding high overhead in the June sky is a fellow we've heard a lot about in Star Dome in the past few months — Hercules. Tacked to the heavens as trophies of combat with Hercules are the previously visited constellations of Cancer the crab, Leo and Hydra the water serpent.

Hercules lies halfway between Arcturus and Vega. A trapezoid or keystone of four third and fourth magnitude stars is the most noticeable shape in this faint constellation. The strong man is usually pictured as standing or kneeling upside-down, his head pointed toward the southern horizon. From the keystone or trunk of his body, two arms extend downward along faint rows of stars. The hero brandishes a club in his right hand and a branch of wood or a three-headed dog (depending on the legend) in his left hand. Two legs protrude from the top of the keystone.

Hercules is the greatest hero and one of the most colorful characters in Greek mythology. His adventures are far more rich and imaginative than anything that those dubbed Italian movies portray. Hercules personifies the cherished ancient Greek qualities of courage, boldness and self-confidence. But he also exhibits far more brawn than brain, acting on impulse rather than stopping to think things out.

Hercules is also a tragic character. From birth to death, the hero's life is constantly made miserable by Hera, wife of Zeus the king of the gods. Because Hercules was born out of one of Zeus' affairs with mortal women, jealous Hera always sought revenge on the warrior.

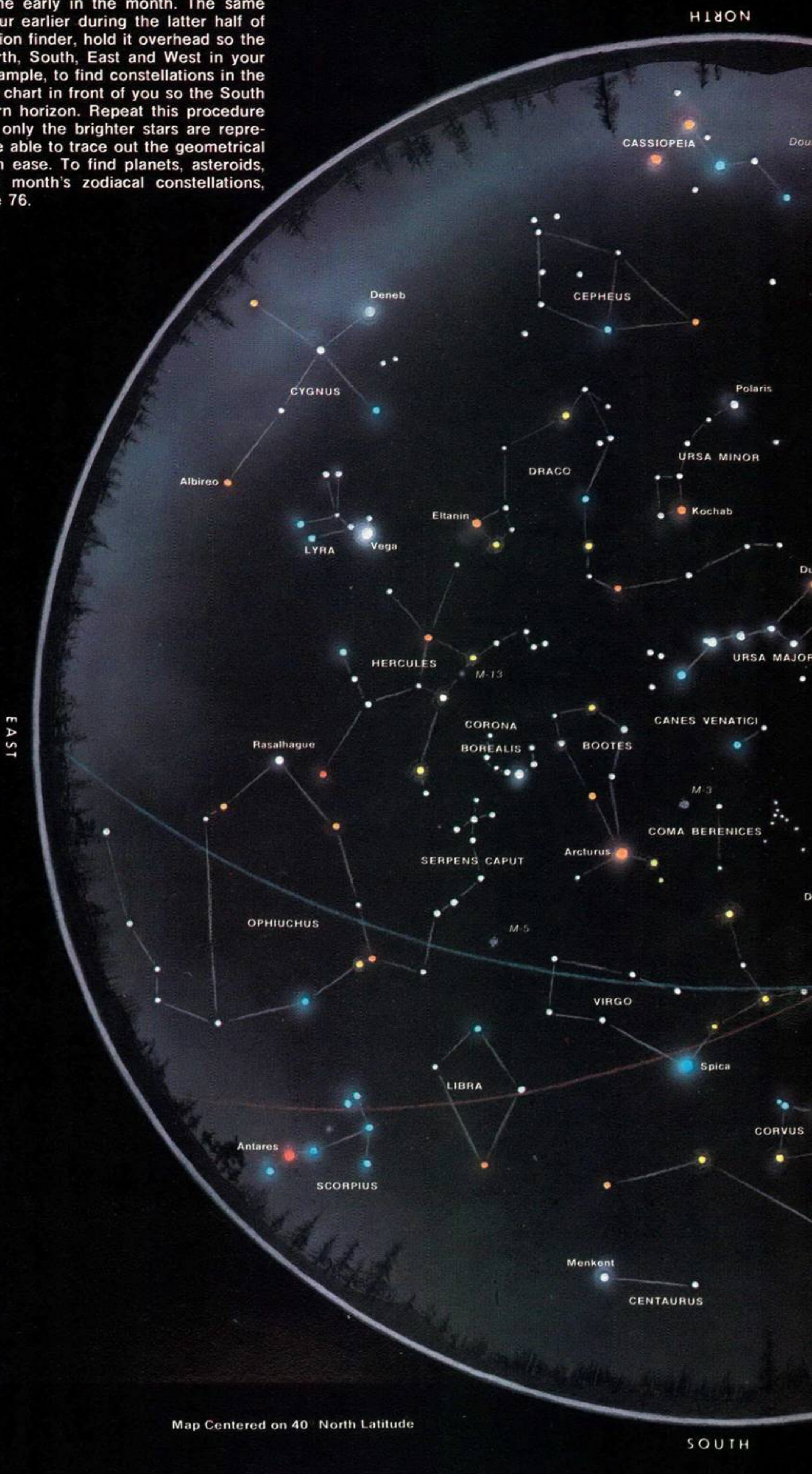
In her most sinister trick, Hercules was made temporarily insane — just long enough for him to kill his wife and children. As penance for these terrible murders, he embarked on 12 extremely difficult and deadly tasks thought up by his cousin Eurystheus (with some help from Hera). On these "missions impossible," the hero battled an almost invincible lion, an annoying crab, a terrifying nine-headed water serpent, the three-headed dog of the kingdom of the dead, and the queen of the Amazons — for her girdle! An especially gruesome task demanded that Hercules clean thousands of cattle stables in Augeias in a single day!

Following these "12 labors of Hercules," the hero continued getting drawn into powerful struggles with such unlovable creatures as a giant wrestler who was roofing a temple with the skulls of his victims, and Mr. Death himself. To return to life a friend who had recently died, Hercules vowed, "I'll wrestle with him . . . if he is not by the grave I will go down to Hades (kingdom of the dead) after him."

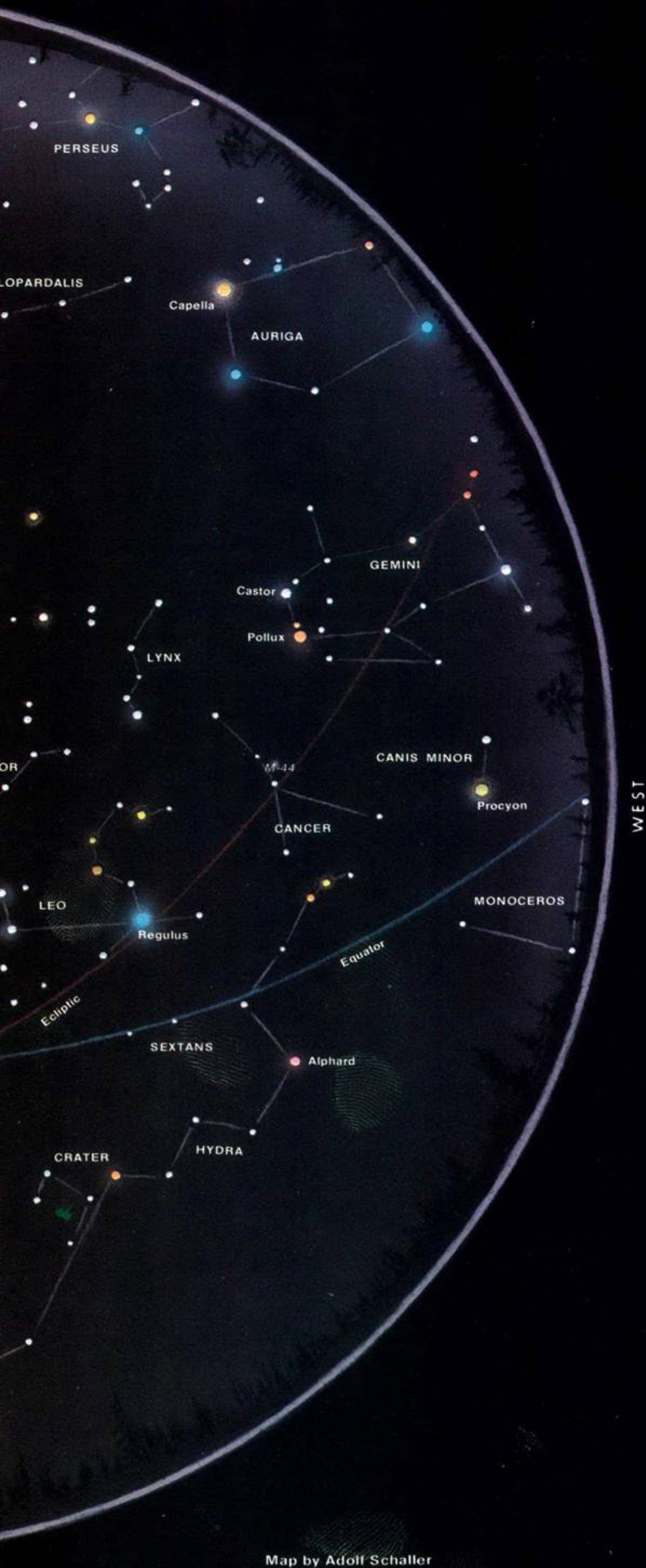
Although Hercules won the first round with Death, the hero's infidelity to his wife Deianeira gave Death a second chance. To punish Hercules, Deianeira presented him with a poisonous magic robe. Even the deadly robe could not kill this mighty hero, but caused him enough pain to want to die. After Hercules sadly mounted his own funeral pyre, the god Zeus summoned a mysterious cloud to carry the hero into the sky as a constellation.

A special prize within this summer constellation is globular star cluster M-13, which can only be found on a clear moonless night in the countryside. M-13 appears as a hazy patch of light floating between

This Star Dome rendering approximates the sky as it appears at about 9 p.m. Local Daylight Time early in the month. The same constellations are visible one hour earlier during the latter half of the month. To use this constellation finder, hold it overhead so the compass points line up with North, South, East and West in your backyard or viewing area. For example, to find constellations in the southern part of the sky hold the chart in front of you so the South compass point faces the southern horizon. Repeat this procedure for East, West and North. Since only the brighter stars are represented in this map, you should be able to trace out the geometrical shapes of the constellations with ease. To find planets, asteroids, etc., visible among the current month's zodiacal constellations, refer to the planet finder on page 76.


NORTH
CASSIOPEIA
CEPHEUS
Deneb
CYGNUS
Polaris
Albireo
DRACO
URSA MINOR
Kochab
Eltanin
LYRA
Vega
HERCULES
M-13
URSA MAJO
EAST
CORONA
BOREALIS
BOOTES
CANES VENATICI
Rasalhague
M-3
COMA BERENICES
Arcturus
SERPENS CAPUT
OPHIUCHUS
M-5
VIRGO
Spica
LIBRA
CORVUS
Antares
SCORPIUS
Menkent
CENTAURUS
SOUTH

Map Centered on 40° North Latitude



Map by Adolf Schaller

the two stars forming the right side of the keystone. The cluster can best be found by using averted vision — the eye's property of making faint objects appear more noticeable when it is not aimed directly at them. Try this with M-13. Look slightly away from the direction of the cluster and it will seem more distinct. Through binoculars, M-13 appears as a ghostly, luminous spot having absolutely no detail. It's hard to imagine that possibly 1,000,000 stars are concentrated within this tiny patch in the sky.

M-13 is one of about 120 known globular star clusters — compact, spherical islands of stars orbiting the center of our galaxy. M-13 recently was in the news as the target of man's first attempt at signaling intelligent civilizations beyond Earth; a message was broadcast toward the cluster late last year (see Astro-News, February 1975). M-13 makes an ideal target, because its closely packed star population can be entirely covered by the relatively narrow angle radio beacon. But don't wait for a reply from anyone inhabiting M-13. Since the cluster is 24,000 light-years away, the astrogram will not arrive until 26,000 A.D.

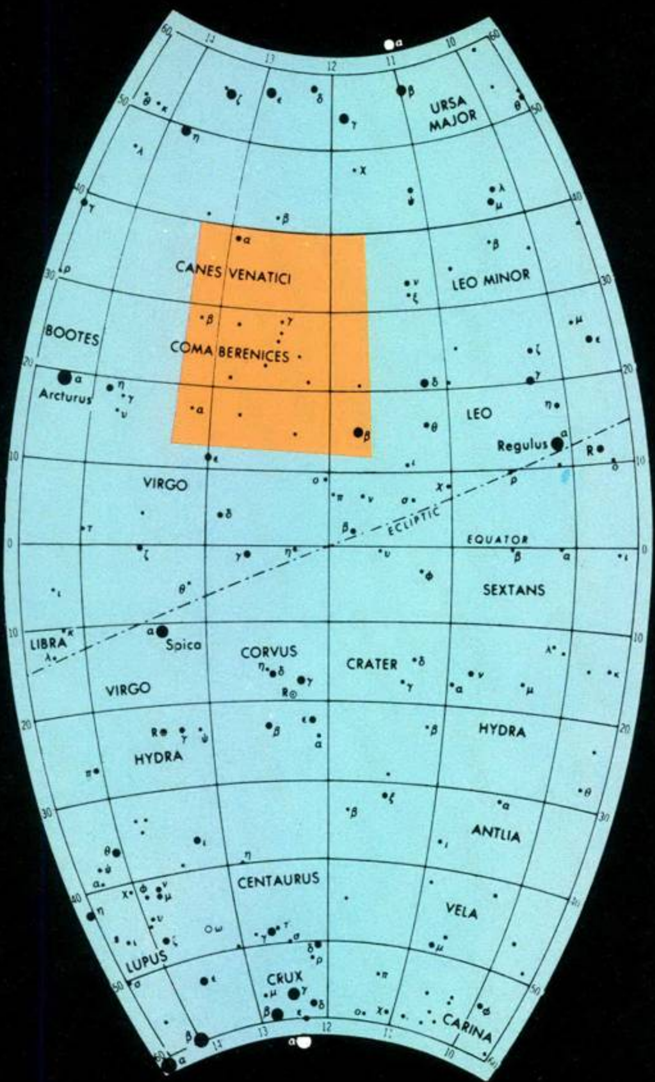
Hercules' left foot is on the head of his neighbor, Draco the dragon. Like all the constellations near the north celestial pole, Draco is visible slinking around the heavens throughout the year. Now he's almost directly overhead.

A closely spaced grouping of four stars marks his head, with the stars Rastaban and orange-colored Eltanin representing two glowing eyes. Draco's head makes a good place for practicing your skill at distinguishing among different star magnitudes. Nearby Vega and Deneb plus the head stars represent the first six apparent magnitudes. Remember that every jump up or down in magnitude means a 2-1/2 times increase or decrease in a star's luminosity *as it appears from Earth.* Eltanin, at second magnitude, appears 2-1/2 times less bright than first magnitude Deneb — which is 2-1/2 times fainter than zero magnitude Vega. In turn, third magnitude Rastaban is 2-1/2 times dimmer than Eltanin, or 16 times (2-1/2 x 2-1/2 x 2-1/2) dimmer than Vega. The other pair of stars in the head represent fourth and fifth magnitudes — the faintest one being 100 times fainter than brilliant Vega.

Behind the head, Draco's body follows an "S" pattern around the Big and Little Dippers. A notable star here is Thuban (it's unmarked, but it can be found halfway between Kochab — an orange star in the top of the Little Dipper's cup — and the star at the end of the Big Dipper's handle).

Five thousand years ago Thuban was the North Star, occupying the spot in the sky where Earth's northern axis points. Today, Polaris (in the tip of the Little Dipper's handle) serves as the North Star. Why the change?

As Earth spins, its axis wobbles much in the same way the spin axis of a slowing down toy top or gyroscope appears to move in a circle. This *precession* of an axis is easy to watch in a toy, but for Earth to


URSA MAJOR
CANES VENATICI
LEO MINOR
BOOTES
COMA BERENICES
Arcturus
LEO
Regulus
VIRGO
ECLIPTIC
EQUATOR
SEXTANS
LIBRA
Spica
CORVUS
CRATER
VIRGO
HYDRA
HYDRA
ANTLIA
CENTAURUS
VELA
LUPUS
CRUX
CARINA

Stars in each constellation are indicated, in order of brightness, with the Greek Alphabet

Letter	Name
α	Alpha
β	Beta
γ	Gamma
δ	Delta
ϵ	Epsilon
ζ	Zeta
η	Eta
θ	Theta
ι	Iota
κ	Kappa
λ	Lambda
μ	Mu
ν	Nu
ξ	Xi
ο	Omicron
π	Pi
ρ	Rho
σ	Sigma
τ	Tau
υ	Upsilon
φ	Phi
χ	Chi
ψ	Psi
ω	Omega

Star Magnitudes
−1
0
1
1½
2
2½
3
3½
4
5
Cluster or Nebula
Variable Star

Map from **Guideposts to the Stars**; reprinted permission of MacMillan Publishing Co., ©1972 by Leslie C. Peltier.

TABLE OF OBJECTS — COMA BERENICES REGION

Double Stars

Star	Mag.	Sep.	R.A.	Dec.
24 Coma Berenices*	5.2, 6.7	20"	12^h33^m	+18°39'
α Canes Venaticorum *	2.9, 5.4	20"	12^h54^m	+38°35'

Globular Cluster

Name	Constellation	Mag.	Diameter	R.A.	Dec.
M-53*	Coma Berenices	7.6	3'	13^h10^m	+18°26'

Galaxies **

Name	Type	Mag.	Size	R.A.	Dec.
NGC-4565*	spiral	10.2	14' x 1'	12^h34^m	+26°16'
M-64*	spiral	8.8	6' x 3'	12^h54^m	+21°57'
M-84	elliptical	9.3	2' x 1'	12^h23^m	+13°10'
M-85	elliptical	9.3	2' x 2'	12^h23^m	+18°28'
M-98	spiral	10.7	8' x 2'	12^h11^m	+15°11'
M-99	spiral	10.1	5' x 4'	12^h16^m	+14°42'
M-100	spiral	10.6	5' x 5'	12^h20^m	+16°06'
M-88	spiral	10.2	6' x 2'	12^h30^m	+14°42'

* Detailed description in Eyepiece Impressions   * * Additional galaxies are tabulated on page 37.

R.A. and Dec. Epoch 1950

trace out one circle on the Star Dome takes an arduous 26,000 years. So for our lifetime and coming generations, Polaris will remain a reliable North Pole marker. Next in line for the honor is the third brightest star in the constellation Cepheus, arriving in this region in 4,000 years. Thuban's turn comes up again in 23,000 A.D.

As a fire-spouting monster having a hide like a Sherman tank, Draco makes an ideal villain in several ancient myths. Hercules fooled the dragon in one adventure and it fought in a fantastic battle between the Titans and the 12 Olympian gods. Since nothing less than the control of the universe was at stake, all kinds of terrible weapons were unleashed: thunder, lightning, earthquakes, monsters with 100 hands! Unfortunately, poor Draco picked the losing side. Zeus' daughter Athena hurled the dragon into the sky where its long snakelike body got tangled around a sky pole.

Contrasting to the tiny, concentrated globular cluster M-13 we pointed out earlier is Coma Berenices, an extremely faint and disperse open star cluster lying halfway between Arcturus and Denebola. Coma Berenices means the "hair of Berenice," believed to be an ancient Egyptian queen. Legend explains that this glittering cobweb of stars represents Berenice's beautiful blonde hair, offered to the gods in gratitude for the safe return of her husband from battle.

Coma Berenices is a real challenge for naked eye observers. Even on a crystal clear night, this cluster is almost impossible to see without using low power binoculars.

Close-up on the Coma Berenices Region

No region of the sky compares to the area we plan to examine this month. Nowhere does a sector of such faint stars contain so many celestial wonders. One of the sky's dimmest constellations, Coma Berenices (pronounced KO-muh berry-NICE-sees) appears like a blank spot between Leo and Bootes. Of the constellations visible from midnorthern latitudes, only Sextans and Sculptor have fainter stars.

The brightest of the faint stars in Coma Berenices is Beta (β) at 4.3 magnitude, closely followed by Alpha (α) at 4.4 and Gamma (γ) at 4.6. On a very clear night, a swarm of fifth and sixth magnitude stars can be identified near and south of Gamma. This gang of suns comprises a galactic star cluster called, simply, the Coma star cluster.

At a distance of 250 light-years, this group is similar to the Hyades in Taurus but twice as far away and, therefore, far less conspicuous. About equal in area to the sky's brightest star cluster, the Pleiades, the Coma group is less than 1/4 as densely populated. The cluster is a really superb binocular object — no other optical aid is suitable for examining it — and summer evenings are ideal for lying back and studying these distant suns sprinkled in the velvet sky.

A confusion in names can occur during discussions of this area. The Coma star cluster is totally different from the Coma cluster of galaxies whose members are exceedingly faint and only well seen on major observatory photographs. The two are totally unrelated and just happen to be in the same area of the sky. However, galaxies *are* sprinkled all over this area — but these are part of the Virgo galaxy cluster, 10 times closer than the Coma group. (Members of the Virgo cluster are discussed in the following section and in Gazer's Gazette.) Why do we see a treasure chest of galaxies here? We seem to be looking out a window to the edge of the universe. Why is this particular sky area a window?

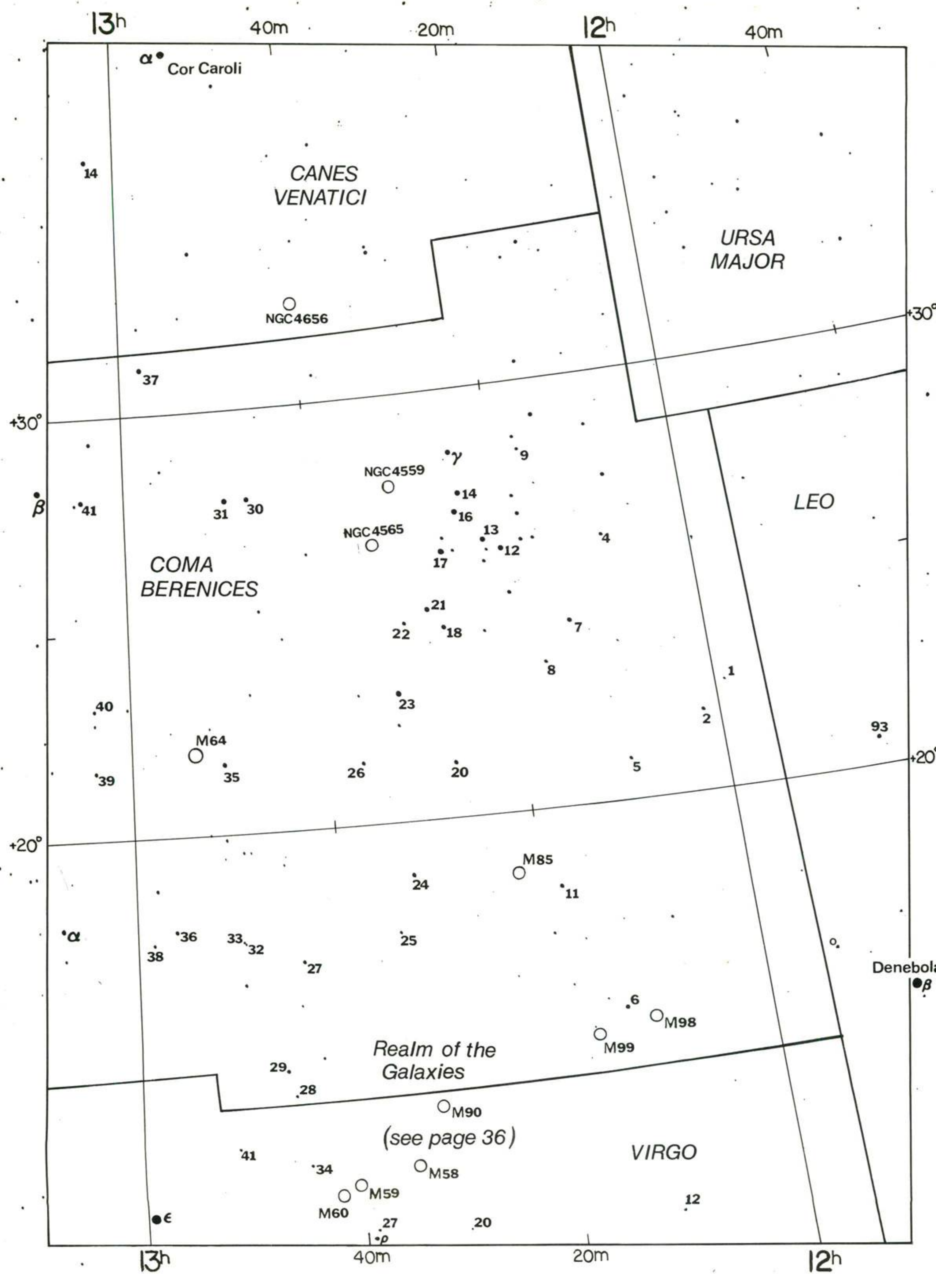
The sun is located nearly in the middle of the 3,000 light-year thick spiral arm, or disk region, of the Milky Way galaxy. When we look away from the disk — especially at a right angle to it — we see relatively few stars and can clearly examine the galaxies beyond. That right angle point (for our solar system) is near the star 31 Coma Berenices. We have fewer stars and interstellar dust to obscure our view here than in any other part of the sky. The opposite sky point is not quite as open because the sun is positioned slightly above the exact center of the galactic plane. The result is that we have our least obstructed view of the universe in the Coma region.

This cosmic window happens to coincide with the Coma and Virgo galaxy clusters — two gigantic swarms of galaxies. One of these contains huge galaxies that are visible in moderate sized telescopes. The entire area — including these galaxy clusters and other fainter assemblages — is known as the "Realm of the Galaxies." For a challenging adventure in amateur astronomy, few endeavors rival a mind expanding ascent into this celestial realm.

Eyepiece Impressions

Cor Caroli

Cor Caroli is one of the most attractive double stars in the sky for a small glass, and as such makes a good opening object before galaxy hunting begins. Overshadowed by its illustrious neighboring double (Mizar in the Big Dipper's handle), this object might be better known if located in some other part of the sky. A striking duo of third and fifth magnitude stars some 20 seconds of arc apart, Cor Caroli is just right in a 2.4 inch refractor at 30 power. Indeed, magnifications much in excess of this on any telescope will spoil the pair's neat or "tight" appearance.


13h
40m
20m
12h
40m
α Cor Caroli
14
CANES VENATICI
URSA MAJOR
NGC4656
+30°
37
+30°
γ
9
NGC4559
14
β
41
31
30
16
NGC4565
13
4
12
17
LEO
COMA BERENICES
21
22
18
7
8
1
40
23
2
93
M64
35
26
20
5
39
+20°
+20°
M85
24
11
α
36
33
32
25
38
27
Denebola β
6
M98
M99
Realm of the Galaxies
29
28
M90
(see page 36)
VIRGO
41
34
M58
M59
M60
12
ϵ
27
20
ρ
13h
40m
20m
12h

Most observers see both the components as white in color with perhaps a tinge of blue. However, there have been considerable differences of opinion here and contrasting hues have been frequently reported. Some early observers even suspect this object, along with a number of other pairs, of actually changing colors with time. Among the combinations listed for Cor Caroli are: both white, both yellowish, white and tawny, yellow and lilac, pale yellow and fawn, pale yellow and pale copper, white and lilac, pale yellow and pale lilac, white and pale olive blue, creamy and fine blue, and yellowish white and pale ruddy!

Such variations are very likely subjective in nature rather than real, and demonstrate the difficulty of color perception when the involved stars are both bright and white. Among the factors affecting color estimates are the training of the eye, type and quality of telescope and eyepiece used, atmospheric conditions, and even the presence of bright artificial or moonlight. Despite the difficulties, observing and recording the colors of the brighter double and multiple stars makes an interesting project for the amateur — especially with objects like Cor Caroli around! What about you — what colors do your eyes and telescope reveal for this pair?

In addition to the visible members of this system, there are also two "invisible" spectroscopic companions; Cor Caroli B is a strange "magnetic" variable whose strong field undergoes intense fluctuations in strength. The entire group is physically related and lies at a distance of 140 light-years from the sun.

NGC-4565

South of Cor Caroli and just east of the large sprinkling of faint naked eye stars forming the Coma star cluster is one of the most striking galaxies in the sky — NGC-4565. A line from 12 through 17 Comae prolonged an equal distance east ends exactly at the galaxy's position. It can also be found directly on a line from Gamma, 1/3 of the way to 35 Comae.

At least 14 by 1 minute in extent, NGC-4565 is quite large but also rather faint at 10th magnitude — requiring careful sweeping in small instruments. A three inch refractor at 45 power will show it on a dark night of good atmospheric transparency. In a four inch reflector at 40 power, this distant edge-on spiral looks like a long vertical sliver of light. If the eye is well dark-adapted, averted vision will reveal a bright nuclear hub and dark rift running much of the length of the galaxy, appearing to cut it in two.

With 8 and 10 inch reflectors, NGC-4565 becomes a marvelous sight! Webb using his 3.7 inch refractor called it "very faint," but in a nine inch reflector described it as an "Extraordinary phenomenon . . . well seen . . . center cut in two by dark absorbing band, and there is a central star." Barns using his homemade 10 inch reflector reported "seen edgewise, with bulbous center and long . . . bifurcated luminous body. Unique!"

Observatory instruments show this remote star citadel just as it looks on its pictures! But even with amateur telescopes, it's both fun and instructive to compare the visual appearance of this and other deep sky objects to their photos. It is often surprising just how much of the photographic detail can be glimpsed by a trained eye.

M-64

Continuing southeast of NGC-4565, we encounter another galaxy having an unusual feature to lure the sky explorer. This is M-64, easily found just a degree northeast of fifth magnitude 35 Comae. Better known as the Black Eye galaxy, this object has an intense dark area of obscuring material near its nucleus which aptly fits its name.

Both large and bright (six by three minutes and ninth magnitude) as galaxies go, M-64 is one of the easiest in its class to locate and observe. Perhaps the best classic description of this object was made by Barns: "like a colossal pendant abalone pearl in rayless void." Again Webb calls this a "magnificent large bright nebula blazing to a nucleus."

In three and four inch telescopes, the nuclear region of the galaxy seems to have a granular or sparkling appearance. Some of the older observers like Sir John Herschel and Lord Rosse even thought they could resolve the nucleus with their large reflectors. This, however, was before the nature of galaxies was known.

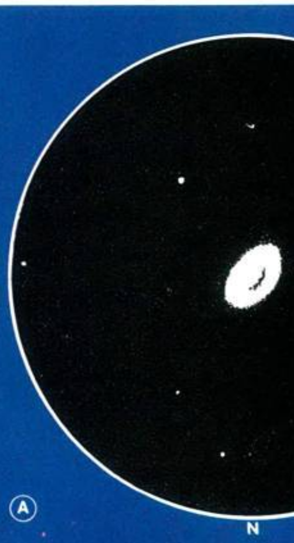
The dark patch itself is somewhat of a challenge to the visual observer in telescopes less than six inches aperture. A four inch reflector at 70 power allows tantalizing glimpses of its presence on transparent nights, and it is obvious in an eight inch reflector at 64 power. This spiral universe is at least 12,000,000 light-years away, and like its numerous neighbors is viewed through the relatively thin sprinkling of stars belonging to our own Milky Way galaxy.

M-53

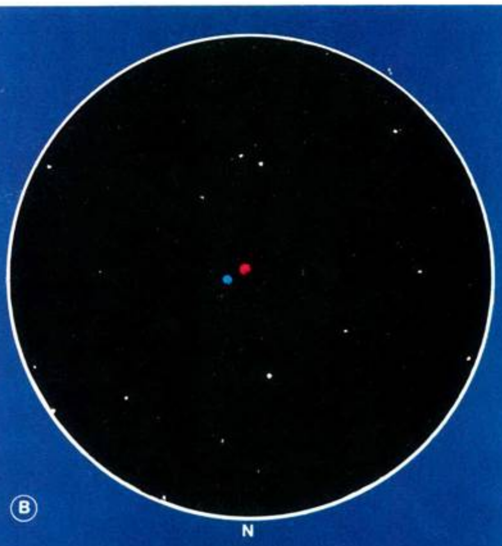
Again sweeping southeast to M-64, we come upon an object that seems like an intruder in the galaxy hunting grounds. This is the globular cluster M-53, located just a degree northeast of fifth magnitude Alpha (α) Comae. At first glance it looks very much like an eighth magnitude circular galaxy three minutes in diameter; closer inspection reveals it to be a tightly packed ball of stars.

Descriptions of M-53 are scarce, but Webb does note "brilliant mass of minute stars, blazing in center. Not very bright at 3.7 inch." A four inch reflector at medium powers in good seeing will resolve the stars at the outer edge of the cluster, and a six inch shows resolution into the center. There are a number of nearby stars within the field including a coarse equal double. These are ideal for critical focusing on the cluster itself, whose individual stars are quite faint.

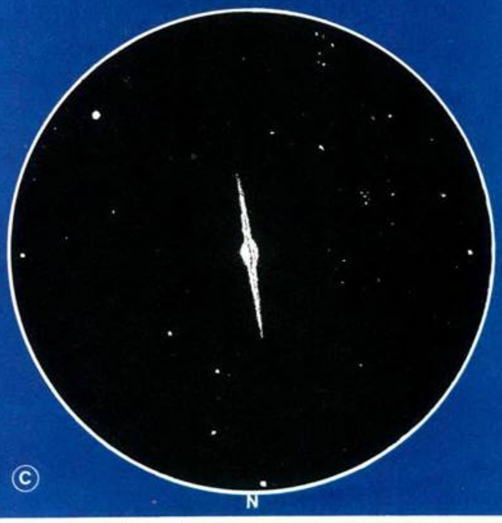
For those observers desiring a test of their skills and instruments, a companion globular designated as NGC-5053 is located just a degree to the southeast of M-53. Although of the same apparent size as M-53, this object is at least several magnitudes fainter than its more populous eighth magnitude neighbor. In



Ⓐ Through a 70 power eyepiece on a six inch Dynascope reflector, M-64 or the Black Eye galaxy resembles its namesake. This bright galaxy's unusually smooth and uniform texture is abruptly broken by a giant black dust cloud bordering half of the nucleus. The field of view is approximately 40 minutes of arc.



Ⓑ The binary star Cor Caroli, brightest gem in Canes Venatici, is one of the sky's finest double stars for small telescopes. This star pair is comfortably separated in a 45 power eyepiece on a three inch Unitron refractor, providing a one degree field of view.



Ⓒ A glowing needle of light identifies NGC-4565, the largest observable edge-on spiral galaxy. In this 40 minute of arc view through a four inch Edmund reflector and 45 power eyepiece, the galaxy appears quite prominent. Its 15 second of arc diameter corresponds to a 90,000 light-year diameter at NGC-4565's distance of 20 million light-years.

fact, most star atlases omit even plotting this elusive stellar sphere. With M-53 placed inside the northwest edge of a low power eyepiece field, NGC-5053 will be at the opposite or southeast side. Can you see it with your telescope?

24 Comae Berenices

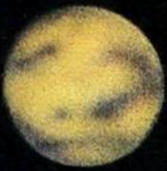
Delighting the eye after a spell of galaxy hunting, the fifth magnitude star 24 Comae consists of a stunning combination of deep orange and blue suns, very much like famed Albireo [Beta (β) Cygni]. It can be found at the top of a triangle formed with the stars Denebola and Epsilon (ϵ) Virginis. Even slight optical aid will show fifth and seventh magnitude stars separated by 20 seconds.

The contrasting colors of this pair are especially vivid in larger amateur instruments. This is contrary to the rule that hues of brighter double stars are best seen in small apertures. Large telescopes with their increased light gathering ability tend to overwhelm the eye with the light of brighter stars, thereby reducing its sensitivity to color. Those observers with, say, 8 or 10 inch scopes should try masking down with cardboard aperture stops having an opening three or four inches in diameter. The resulting transformation in image structure, especially at high magnifications, is surprising. Subtle differences of hue among the components that were totally unsuspected at full aperture become visible at a glance.

For a really out-of-this-world experience, combine your telescope with a low power (40 or 50 power) wide field eyepiece (at least one degree or more) and wait for a dark transparent evening without the moon in the sky. When the opportunity comes, slowly sweep the region of sky covered by our Close-Up map. Galaxy upon galaxy will pass in review — often several being visible in the field of view at the same time. These distant outposts of space and time lure the observer upward and outward. Sweep after sweep unfolds majesty, and soon we lose track of time and place. We are totally lost among the galaxies!

In viewing these faint blurs of light from far beyond out Milky Way, we observe them with both our eyes and mind. It is what these objects represent that really counts — and not their feeble appearance in our telescopes. In the words of the noted French scientist and philosopher Jean Perrin, "It is indeed a feeble light that reaches us from the starry sky. But what would human thought have achieved if we could not see the stars . . . ?"

Planet Finder



Ⓐ Mercury

June	1
R.A.	5^h30^m
Dec.	+22°36'
Mag.	+2.3

Ⓑ Mercury

June	15
R.A.	5^h03^m
Dec.	+18°42'
Mag.	+2.5

Ⓜ Mars

June	1	15
R.A.	0^h34^m	1^h12^m
Dec.	+1°56'	+5°54'
Mag.	+0.9	+0.8

Ⓒ Cere

June	1	15
R.A.	2^h40^m	3^h01
Dec.	+1°21'	+1°2
Mag.	+9.1	+9.1

Ⓝ Neptun

June	15
R.A.	16^h3
Dec.	-20°2
Mag.	+7.7

SUN

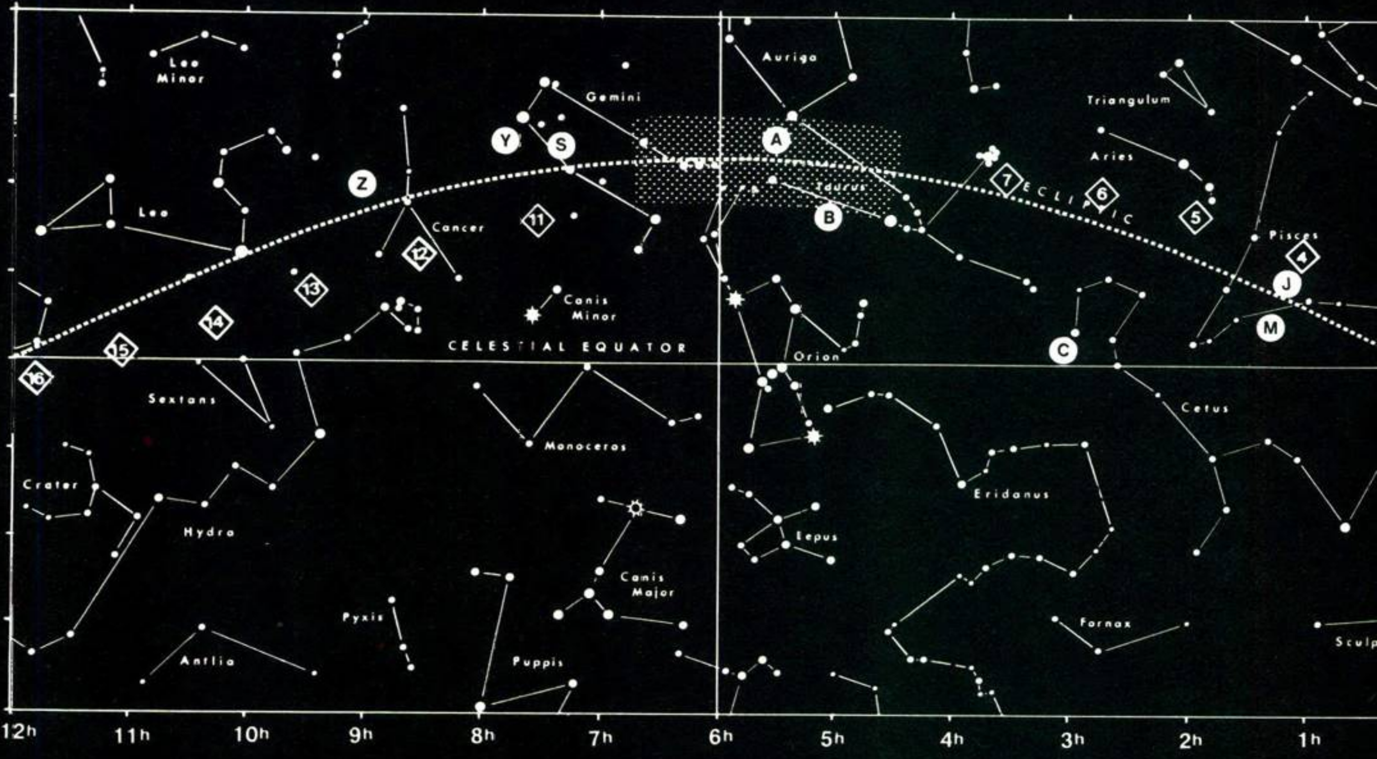
The sun is within the stippled zone throughout the month. Planets and stars near this area are not easily seen.

Ⓢ Saturn

June	1	15
R.A.	7^h14^m	7^h21^m
Dec.	+22°14'	+22°03'
Mag.	+0.4	+0.4

Ⓤ Uranus

June	15
R.A.	13^h46^m
Dec.	-10°27'
Mag.	+5.7



Leo Minor
Gemini
Auriga
Triangulum
Aries
Leo
Y
S
Z
A
Cancer
11
12
13
14
15
16
Taurus
B
7
ECLIPTIC
6
5
Pisces
4
J
M
Canis Minor
CELESTIAL EQUATOR
Orion
C
Sextans
Monoceros
Cetus
Crater
Hydra
Eridanus
Lepus
Canis Major
Pyxis
Fornax
Sculp
Antlia
Puppis
12h
11h
10h
9h
8h
7h
6h
5h
4h
3h
2h
1h

Map by Raymond G. Coutchie

The chart shows the positions of the moon, planets and brightest asteroids for the current month. Letters within the circles correspond to the letters beside each object in the data section above the map. Additional information about each object is given there. R.A. = right ascension and Dec. = declination, the two coordinates used to locate astronomical objects. The general coordinate system is indicated around the edge of the map. Mag. = magnitude, a

June 1975

Ⓥ Vesta

une	1	15
R.A.	23h32m	23h49m
Dec.	+1°19'	+1°19'
Mag.	+7.6	+7.6

Ⓙ Jupiter

June	1	15
R.A.	1h04m	1h13m
Dec.	+5°33'	+6°27'
Mag.	-1.8	-1.9

Ⓨ Venus

June	1
R.A.	7h51m
Dec.	+23°33'
Mag.	-3.8

Ⓩ Venus

June	15
R.A.	8h54m
Dec.	+19°50'
Mag.	-3.9

Ⓟ Pluto

June	15
R.A.	12h49m
Dec.	+13°05'
Mag.	+14

First Quarter

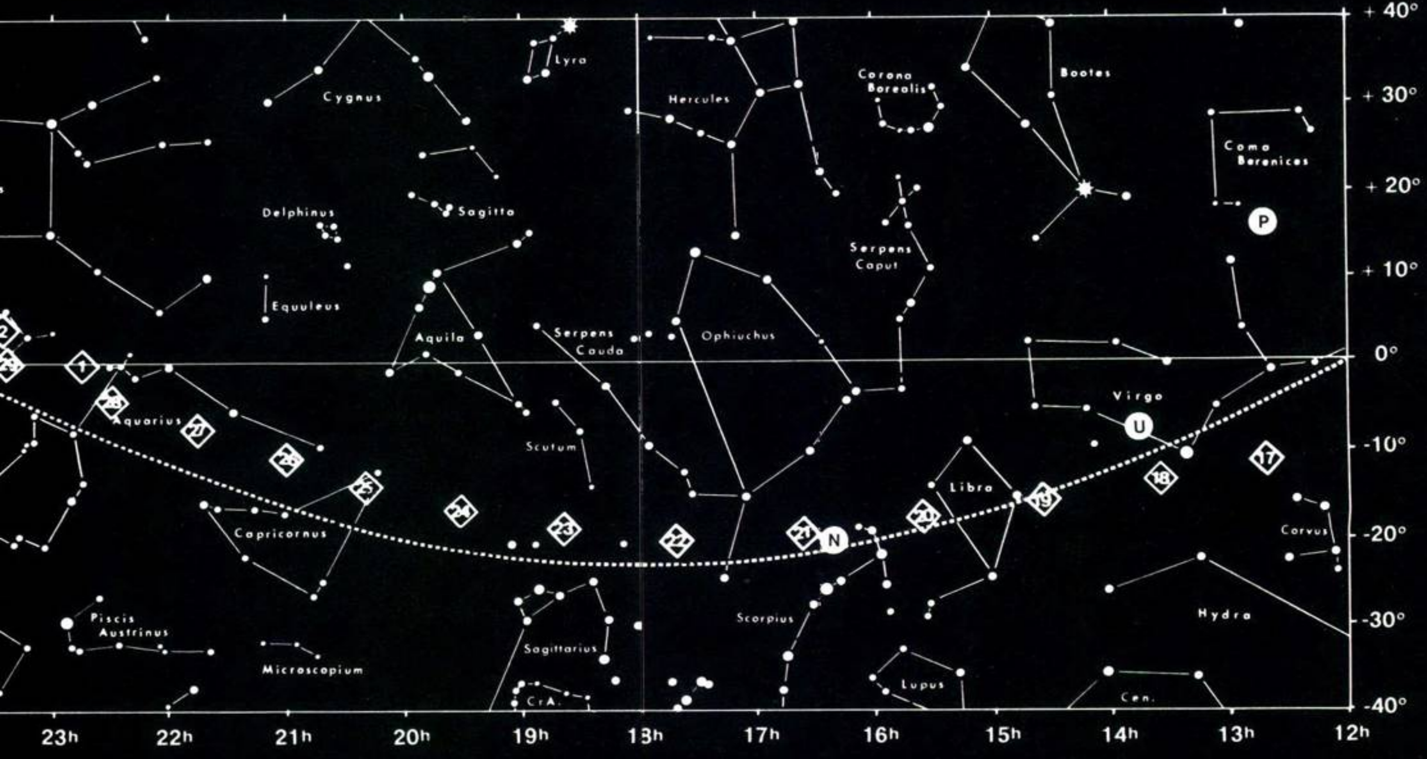
June 16

Full Moon

June 23

Last Quarter

June 1



Lyra
Cygnus
Hercules
Corona Borealis
Bootes
Coma Berenices
Delphinus
Sagitta
Serpens Caput
Equuleus
Aquila
Serpens Cauda
Ophiuchus
Virgo
Aquarius
Scutum
Libra
Capricornus
Corvus
Hydra
Scorpius
Piscis Austrinus
Sagittarius
Microscopium
Lupus
CrA.
Cen.
P
U
N
1
2
3
17
18
19
20
21
22
23
24
25
26
27
28
+40°
+30°
+20°
+10°
0°
-10°
-20°
-30°
-40°
23h
22h
21h
20h
19h
18h
17h
16h
15h
14h
13h
12h

Artwork by Victor Costanzo

measurement of the object's brightness. (The minus magnitudes indicate very bright planets.) The diamonds with numbers within them indicate the position of the moon for each day of the month; the numbers correspond to the dates. Positions of the planets are for the 15th of the month except for Mercury and Venus which are shown on both the 1st and 15th. Certain areas of this map and the Star Dome chart overlap each month.

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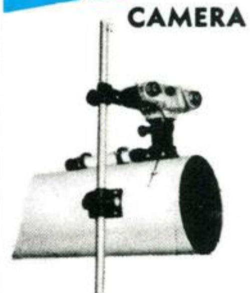

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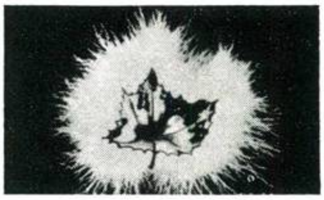

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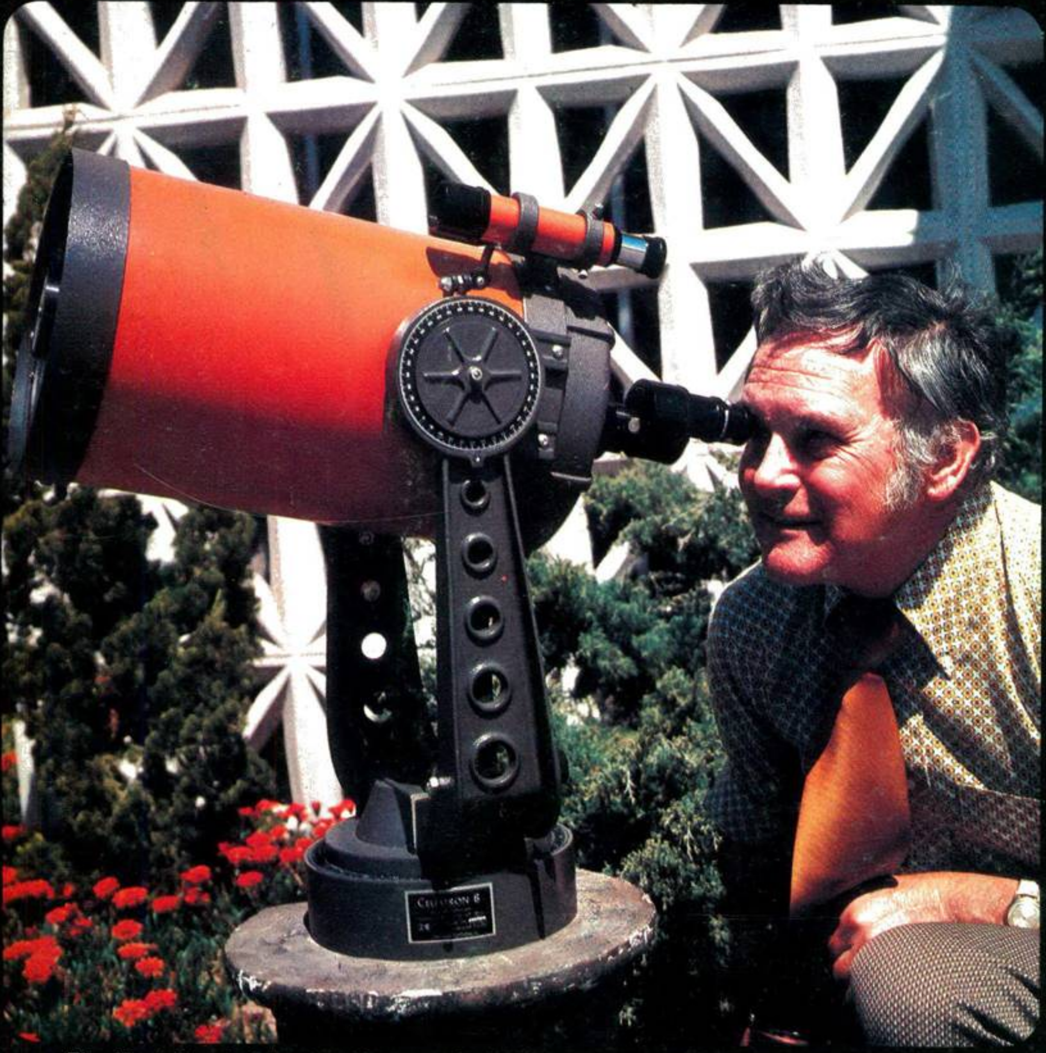

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